A STUDY OF SOIL MOISTURE IN RELATION TO ABSORPTION AND TRANSPIRATION BY CITRUS

By

ROBERT CHUNG-JEN KOO

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I. INTRODUCTION

Water is often the principal limiting factor in the production of citrus in many sections of the world. In Florida the average total annual precipitation is more than sufficient for the satisfactory growth and production of citrus fruits; however, uneven distribution of rainfall throughout the year often necessitates irrigation. In order to use irrigation intelligently it is important to understand some of the fundamental relationships between soil moisture and plant growth.

The studies which were included in this thesis covered the following phases:

A. How moisture is lost from the soil once added to it, either through precipitation or irrigation. Attempts were made to break down the sources of moisture loss and to estimate them quantitatively.

B. The effects of varying soil moisture contents on the rate of transpiration by the plants.

C. The usefulness of the soil moisture tensiometer for measuring soil moisture fluctuations as an indicator to determine when to irrigate.

II. REVIEW OF LITERATURE

A. Certain Soil Moisture Constants

Soil moisture is usually measured as mass of water per unit mass of dry soil. It may be expressed either as a percentage on a dry weight basis or as a ratio of volume of water to unit volume of dry soil. The ratio of water to dry soil, without reference to some standard or base for comparison is, in itself, of little value. A soil may have a high moisture content, yet from the percentage soil moisture one cannot know whether the soil contains water available to plants or whether additional water can be stored in it. The water available to plants is that which is present in the soil between two values which are constants for any given soil type—the field capacity and the permanent wilting percentage.

1. Field Capacity.—The field capacity is the amount of water held in the soil after excess water has drained away and the rate of downward movement of water has materially decreased. This usually takes place within two to three days after a rain or irrigation in pervious soil of uniform structure and texture (102). Soils may drain slowly for a long time after water is applied, but this movement is so slow, as compared to the rate of extraction of water by plants, that for practical purposes it can be said that a soil under a given set of conditions has a certain field capacity. Richards (74), however, has pointed out that some soils do not have a field capacity as the term is ordinarily defined, for there does not appear to be a definite moisture content at

which gravitational movement of moisture becomes negligible.

Of the numerous factors affecting field capacity, the most important are texture, uniformity, and depth of soil. Early work by Alway and Neller (2) showed that if a fine textured soil overlaid a coarse soil, the zone immediately above the coarser layer would have a higher field capacity than the clay would have if it were uniform throughout. Veihmeyer and Hendrickson (99) stated that a shallow soil could hold more water at a unit depth at field capacity than a deeper soil of the same kind, but this effect was not marked in soils deeper than about two feet.

Coleman (17) believed that a soil must be wetted 12 to 30 inches before the surface layer would have a moisture content as high as its field capacity, and shallow irrigation and drainage of short soil columns in the laboratories did not necessarily provide valid measures of field capacity. Results of laboratory studies of field capacity are often higher than that actually measured in the field. Coleman (18) reported that when small soil blocks are drained on a porous ceramic cell under a moisture tension of one-third atmosphere, the moisture retained in the blocks could be related to the field capacity of the same soil determined under natural conditions.

Field capacity is actually not a fixed value but one on a time-drainage curve--a condition of such slow water movement that the moisture content does not change appreciably between applications of water.

The term "moisture equivalent" was introduced by Briggs and McLane (10) to denote the water content of soil which has been subjected to a centrifugal force of one thousand times gravity for 30 minutes.

Its utility arises from the fact that it approximates the field capacity of fine textured soils, although not of sands (97). It is easy to obtain and fairly reproducible. Since the method is arbitrary and the results obtained are largely dependent on the procedure used, considerable attention has been given to it. The size of sample used, i.e. the height of the column of soil in the centrifuge cup, has been shown (48, 83, 94) to affect the value of average moisture content of the sample. Veihmeyer and Hendrickson (97) have studied various other factors that affect the moisture equivalent determination. They concluded that the more important ones were size of sample, oven drying, and fragmenting the sample.

Many have reported results of tests which indicate that the moisture equivalent is a close approximation of field capacity (15, 64, 71, 86, 97), but Veihmeyer and Hendrickson (97) have shown that below 12-14%, the moisture equivalent seems to be less than the field capacity. Work and Lewis (105) found that the moisture equivalent of certain Oregon soils was not equal to field capacity, and such a relation should not be assumed without actual determinations. Browning (13) reported that the ratio of field capacity to moisture equivalent of certain West Virginia soils was unity in the vicinity of moisture equivalents of 21%, more than unity for soils with moisture equivalents below 21% and less than unity for those with moisture equivalents above 21%.

A number of other methods have been suggested by various workers for the determination of moisture equivalent (7, 8, 9, 79, 85). How-

over, all these methods have certain disadvantages and have not been used extensively.

2. Permanent Wilting Percentage.—The moisture content of the soil at the time when the leaves of plants growing in that soil first become permanently wilted has been variously designated as the "wilting point", "wilting coefficient", "wilting percentage" and "permanent wilting percentage". It denotes the lower limits of the soil moisture available to plant. The term was first introduced by Briggs and Shantz (11) who studied 20 soils and made some 1,300 trials on the availability of water to plants. They concluded that on a given soil all plants reduced the moisture content of the soil to about the same extent when permanent wilting was attained. The residual moisture in the soil at the time plants permanently wilted was, therefore, a soil characteristic.

Briggs and Shantz' conclusion that all plants wilt at the same moisture content when grown on the same soil has been questioned by a number of workers, especially in the field of forestry. Brown (12) and Caldwell (16) in separate investigations found that plants growing in the open wilted at higher soil moisture contents than plants growing in the shade with lower rates of transpiration. Shive and Livingston (90), who grew several species under various degree of shading, found that the soil moisture content at permanent wilting was lowest in the shade and highest in full sun. These workers believed that permanent wilting was determined by climatic and not by soil moisture conditions. Lane and McComb (57) found that the permanent

wilting percentage was lower for grass than for trees when grown in pots. Powells and Kirk (30) reported that pine seedlings reduced moisture content of a soil to a lower percentage than sunflowers. Koketsu (52, 53) studied the foliar transpiring power of wheat and soybean plants and determined soil moisture at permanent wilting. He found that the soil moisture at the time of permanent wilting was not constant for a given soil but seemed to be affected by the characteristics of the plant. Hendrickson and Veihmeyer (42), after testing many plants by growing them in the same kind of soils in small containers and in field trials, found the wilting percentage of a particular soil was remarkably constant, regardless of the size of containers, species of plant, season of the year or the degree of exposure. Furr and Reeve (31) obtained similar results. These results substantiate the conclusion of Briggs and Shantz, which aside from some of the exceptions noted now seems to be accepted by most investigators.

Plants growing in containers or in the field continue to use some water after they are wilted. However, water loss at this point is so slow that if it is plotted against time, the curve is practically horizontal. The permanent wilting percentage is then not a point but a narrow range of soil moisture when the plants wilt. Furr and Reeve (31) interpreted this range as the distance between the first permanent wilting point and the ultimate permanent wilting point. By first permanent wilting point they meant "that percentage of soil moisture at which forces acting on the water in the soil are at approximate equilibrium with the forces acting on the water in a plant which is at that stage of

turgor at which vegetative growth practically ceases." As a second check on the time of first permanent wilting they recommended daily measurements of stem elongation, since stem elongation usually ceased at the time that the first pair of leaves wilted permanently. Taylor, Blaney and McLaughlin (93) proposed the term "ultimate wilting point" to designate the soil moisture content when all the leaves have wilted and define the wilting range as the range in moisture content of the soil between the wilting coefficient and the ultimate wilting point. Hendrickson and Veihmeyer (42) showed that this range did not exceed 1 per cent for fine-textured soils or 0.5 per cent for coarse-textured ones. They also showed in the same study that the permanent wilting percentage was the same "whether determinations were made on entire plants or on plants with a single leaf or a pair of leaves."

The gravitational water in saturated soil is readily available to plants but is seldom present long enough to contribute much to plant growth. For most plants, then, the water readily available for growth is the capillary water in the range between the field capacity and the permanent wilting percentage. For this reason Veihmeyer and Hendrickson (103) maintained that the field capacity and the permanent wilting percentage were the only soil moisture constants of any practical value for consideration in connection with plant growth. They have proposed to use the permanent wilting percentage as a reference for the measurement of soil moisture (101).

Soils show great variations in the range of readily available moisture, but sandy soils generally have a narrow range while clay soils

have a wider range. Kramer (55) reported a pure sand having only 2 per cent while a clay in contrast contained 19 per cent of readily available moisture. However, not all soils with high field capacity and moisture equivalents have a high percentage of readily available moisture. Veihmeyer and Hendrickson (100), studying a California clay soil, found a moisture equivalent of 31 per cent and a permanent wilting percentage of 25 per cent, leaving only 6 per cent readily available moisture.

B. The Effects of the Availability of Soil Moisture on Rates of Growth and Transpiration of Plants

The conclusion that there is a minimum soil moisture content below which plants do not obtain water fast or easily enough to maintain normal growth has general acceptance. There are, however, wide differences of opinion and much controversy as to the availability of water between the field capacity and the permanent wilting percentage. On the one hand, it is held that water is equally available to plants throughout the whole of this range; on the other, that plants respond favorably to high soil moisture conditions and that adverse effects will result as the water content decreases.

Hendrickson and Veihmeyer (38, 39, 40, 41, 43) have reported results of a number of experiments with several species of fruits. Their results indicated that the growth and quality of fruits were not affected by the moisture content of the soil unless it fell to the wilting range. They concluded that water was either available or not available to plants, and that it was equally available over the entire range from the field capacity to the permanent wilting percentage.

Similar results were also reported by Hendrickson (37), and Overley, Overholser and Haut (68) observed no variation in stomatal response between the wilting point and field capacity in prunes and apples respectively. However, Oppenheimer and Elze (69) and Mendel (65) found that the midday closure of stomates in citrus occurred earlier when the soil moisture supply became less adequate.

Beckett, Blaney and Taylor (5), from results of studies with citrus and avocado, concluded that as long as the soil moisture was above the permanent wilting point, the moisture content had no measurable effect on the rate of moisture extraction. Furr and Taylor (32) working with potted lemon trees grown under relatively uniform temperature and relative humidity, found the rate of transpiration was not affected over a wide range of soil moisture, but decreased when the moisture reached just above the permanent wilting percentage. However, in the field the same authors found that the rate of growth of the fruit decreased before the moisture content of all the soil in the top foot was reduced to the permanent wilting percentage.

Jenson (45) believed that the volumes of lemon fruits were related to the amount of available soil moisture. On the other hand Halma (35) showed that Washington navel oranges had practically the same fruit size in two plots, one of which was irrigated after the establishment of a definite water deficit in the leaves, while the other was watered before the deficit occurred. In another report Halma (36) showed that the weekly growth increment of fruits followed the same general direction as the weekly soil moisture curve and that the

"relative saturation deficit" in the leaves showed an inverse trend, but factors other than soil moisture affected the "relative saturation deficit" in the leaves to a lesser extent than in the fruits. Oppenheimer and Elze (69), after studying several physiological indicators for irrigation of citrus trees, concluded that "water saturation deficit of leaves" was not satisfactory as an index. A similar conclusion was drawn by Ziegler (106).

Additional studies indicating the equal availability of soil moisture down to the permanent wilting percentage include these of Finch and Van Horn (27), who noted that the percent moisture in mature leaves of pecan (growing under orchard conditions) was nearly constant regardless of differences in soil moisture when conditions for maximum transpiration were obtained. Doneen and MacGillivray (26), reported that seeds of many species of vegetables germinated equally well over the entire range of moisture content from the field capacity to the permanent wilting percentage. Seeds of few species, however, germinated better at one or two per cent above field capacity, and celery seed was found not to germinate at all in the lower range of soil moisture.

The apparent equal availability of soil moisture over the entire range is explained by Kramer (56) on the basis that "there is but a small change in the forces with which water is held by the soil over the range from field capacity to permanent wilting percentage. The permanent wilting percentage occurs at the moisture content where these forces begin to increase very rapidly, and a small decrease in soil moisture therefore is accompanied by a very rapid increase in the force

required to move water from soil to roots".

Considerable evidence is also available indicating that soil moisture is not equally available to plants over the entire range from field capacity to permanent wilting percentage. Schneider and Childers (84) measured transpiration and photosynthesis of apple leaves and found that the rates were affected by changes in amounts of readily available moisture. Similar results were also reported by Loustalot (61) with pecan leaves. Magness, et al. (62) found the growth rate of apples was reduced when the driest part of the root zone approached the permanent wilting percentage, which was long before the entire root zone was dried to that point. Stomatal behavior was also affected by soil moisture, the stomates being open for a shorter period each day in dry than in moist soil. Similar results of stomatal behavior in peach leaves were reported by Jones (47). Aldrich and Work (1) and Lewis et al. (59), working with very heavy soil, reported close correlation between the rate of growth of pear trees and the soil moisture content in the upper three feet. There was a reduction in the rate of growth of fruit when the soil moisture dropped much below about 70% of the readily available moisture. Schopmeyer (87) showed that the transpiration rate of loblolly and short leaf pines grown in containers decreased with decreasing soil moisture content before the permanent wilting percentage was reached. Crowther (21) found that high water level increases the internode length and also the number of flowers of cotton plants.

Martin (63), growing sunflower plants in pots, found that the rate of transpiration per unit of leaf surface was ordinarily affected

when about two-thirds of the available moisture had been removed. Cykler (22) grew potatoes in tanks and concluded that top growth was independent of moisture content as long as available moisture is present, but that high yields could not be obtained unless the soil moisture were kept at a high level and not allowed to fall below one half the range between field capacity and permanent wilting percentage. In a later paper (23) he concluded from field trials that the moisture content should not be reduced below two-thirds of the available moisture. Davis (24) showed that the growth of young maize plants was slowed by decreasing soil moisture and ceased before the soil moisture content reached the permanent wilting point. He (25) also showed that the growth of nut grass appeared to be checked by decreasing availability of water in soil which was always above the permanent wilting percentage. Ayers, Wadleigh, and Magistad (3) and Wadleigh and Ayers (104) from studies with beans in 10-gallon cans, showed that plant growth was inhibited as the soil moisture tension at the time of irrigation increased, even though the moisture content never actually reached the permanent wilting percentage.

It seems that the contradictory opinions concerning the availability of water held by various investigators result at least partly from differences in soil type used, differences in opinion as to what constitutes permanent wilting, and differences in interpretation of the data.

C. The Soil Moisture Tensiometer

The ability of soil to retain water as soil moisture is a funda-

mental soil property. Because of the attraction of soil particles for water, they will hold a film of moisture against strong opposing forces. At any point below saturation, soil moisture is under a tension analogous to the tension in a liquid held by capillarity in a tube. This capillary tension increases from zero in a completely saturated soil to a very high tension value in air-dry soil.

Of numerous soil moisture measuring devices, the soil moisture tensiometer is the most unique in that it measures a property of soil water which is directly related to the work plants must do to obtain water from the soil. Gardner (33) was among the first to relate the capillary potential function proposed by Buckingham (14) to measurements obtainable in moist soils with porous cups and vacuum gages. Kornev (54) was probably the first one to employ the use of porous cup and manometer to measure quantitatively what he termed the "absorbing power" of soils. Joffe and McLean (46), following Kornev's method, used a porous burned clay cup filled with water and connected to a mercury manometer for measuring "suction force" and suggested that the method could be used indirectly for determining the colloidal content of soils. Shaw (89), using the same method, found that the maximum mercury column rise obtainable was determined by the properties of the apparatus and not by the colloidal content of the soil. In other words, the tension developed in the manometer is the same as though it were lifting water from a free water surface. It is now generally accepted that over a certain range of soil moisture contents, water in a porous cup which is filled and connected to a manometer will come to pressure equilibrium

with the soil (74).

Numerous workers (19, 44, 51, 85, 88) have contributed to the development of tensiometer but Richards and coworkers (72, 75, 77, 78, 81, 82) have made a major contribution in this field. Tensiometers have been used by various workers for measuring soil moisture under field, greenhouse and laboratory conditions. One of the chief limitations in their usefulness is the rather limited range of tension over which they are capable of operating. The tension range covered by tensiometers extends from 0 to 850 cm. of water, or about 0.85 atmosphere. This is only a small fraction of tension range over which soil moisture is available for plant growth, since the wilting percentage corresponds approximately to 15 atmospheres (79). The limitation of the useful range appears less severe when stated in terms of available moisture content range of the soil. Richards and Weaver (80) believed that in the finest textured soils the tension range of 0 to 0.85 atmosphere covered about 50% of the available moisture content range. For the coarser sandy soils the tensiometer might cover more than 90% of the available moisture content range. The tension values registered on the mercury manometer are only related to the available moisture. The unavailable moisture, whether its quantity be large or small, has no effect on tension values. Results reported by Stoeckler and Aamodt (92) and Kelley et al. (50) seem to substantiate this belief.

Kelley et al. (50) compared tensiometers, Bouyoucos blocks, thermal units, and gravimetric sorption blocks for measuring soil moisture under field conditions. They found that the tensiometers measured

the soil moisture tension most accurately between 0 and 850 cms. of water. Richards and Huberty (76) studied soil moisture in citrus orchards with tensiometers and found these instruments useful in studying the depth of moisture penetration and rates of extraction by the roots. Instruments installed at depths of 4 feet or more stayed on scale all year, while those at 1-foot levels usually went off the scale before irrigation.

Haise and Kelley (34) reported wide diurnal fluctuations of tensiometers. These fluctuations became greater as the instruments were installed closer to the surface. Richards and Neal (77) reported similar findings, which they explained on the basis of differences in the temperatures of the soil and of the water in the tensiometer system. The effect of diurnal fluctuations can be minimized by making readings at the same time of day, preferably in the morning, so as to follow a period of slow temperature change.

III. A QUANTITATIVE STUDY OF MOISTURE LOSSES IN THE FIELD

In any study of soil moisture and plant relationships, one of the main objects is to find out the amount of water a particular plant or a particular species of plant will use. Likewise in the study of water available to citrus trees, one is interested to know how much water a tree will use over a certain period of time. A problem of this nature can be studied without too much difficulty for annual plants where controlled experiments can be set up either in a greenhouse or in small plots. Such a study for tree crops grown in the field, however, involves factors which often cannot be controlled or regulated. Therefore, each factor involved must be studied separately and the resultant data assembled and fitted together to arrive at an answer for the problem as a whole.

The quantity of water lost from any soil must equal or exceed the amount added to it or the soil may become fully saturated with water. In areas where the loss of water far exceeds the amount added, conditions become unfit for plant growth. The empirical formula for moisture balance in the soil is

Moisture added (Precipitation + irrigation) $\rightleftharpoons$ Moisture lost (Runoff + percolation + evaporation + transpiration)

In the present study attention was directed at evaporation and percolation. No study of runoff was made because the amount was negligible on the sandy soils studied. Since it is almost impossible to measure directly the amount of transpiration of large citrus trees with any accuracy over a period of time, it was estimated by substracting the

sum of evaporation and percolation from the total quantity of water lost.

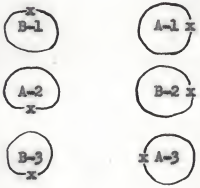
A. Study of Soil Moisture Fluctuations

All the experiments included in this thesis were conducted at the University of Florida Citrus Experiment Station at Lake Alfred, Florida. This experiment was set up using 6 plots of one of the irrigation experiments (Block XIX). The block is planted with grapefruit (Citrus paradisi), of which 7 rows are Marsh (seedless) and the remaining 6 rows Duncan (seeded). All the trees were budded on rough lemon rootstock and planted in 1937. The 6 plots used in this study were selected from the Marsh trees. These plots were randomized so as to represent the entire block. Half of the plots were to receive no irrigation at all, while the remaining half would be irrigated during November-December, January-February, and at petal fall, if the soil moisture content should fall below 2 per cent. There was sufficient precipitation during the winters of 1951-1952 and 1952-1953, so that no irrigation was applied. The only irrigation applied during the course of the experiment was in May 1952, when all the trees were irrigated uniformly.

1. Method of soil sampling and moisture determination.--One of the difficulties involved in the study of water relations on Lakeland fine sand is the wide variations observed in the moisture contents from one location to another. In order to obtain a representative sample it is necessary to collect soils from a number of points from varying

directions under the tree as well as different parts of the block.

Six trees were used in each plot for soil moisture determinations. They were designated as trees A-1, A-2, A-3 and B-1, B-2, B-3 as shown in the following diagram:



x——starting point of sampling

Samples of soils were collected from the A and B trees alternately. Samples from each plot were made up of a composite of borings from soil around three trees. In order to obtain samples as representative as possible, the initial starting point for each tree varies 90 degree from the previous tree in a clockwise direction. Thus, if the initial starting point for tree A-1 was east, tree A-2 would start from the south, etc. In this way each set of samples from "A" trees would be composed of 5 borings on the east and south sides and 4 borings on north and west sides of the trees, while for the "B" trees, the numbers would just be the reverse. Each new sampling point was approximately 8 inches from the previous one, moving in a clockwise direction. A marker was used for each tree to indicate the place of previous sampling. Samples were collected just beyond the drip of the tree at the following depths:

0-6, 6-12, 12-18, 18-24, 30-36, 42-48, 54-60, 66-72 inches. A 6-foot stainless steel soil tube approximately one inch in diameter with a hardened tool steel tip was used for sampling. Samples were collected two or three times a week depending on the pattern of rainfall.

Samples were brought into the laboratory in aluminum cans. They were weighed with minimum delay, dried in an oven at a temperature of 110° C for not less than 24 hours and weighed again. The percentage of soil moisture was calculated with the following formula:

$$\text{Soil moisture } \% = \frac{\text{fresh sample weight} - \text{oven dry weight}}{\text{oven dry weight}} \times 100$$

2. Results.—Wide variations of soil moisture contents were observed throughout the experiment in different plots. Since no irrigation was applied during the winters of 1951-1952 and 1952-1953, and the only irrigation applied was in May 1952 when all the trees were irrigated uniformly, the treatments received in all the six plots were identical. The data are presented and calculated from the average of six plots. As a result the error in sampling caused by variations in moisture content is greatly reduced by the increase in size of sample. Soil moisture determinations from November, 1951 through February, 1953 are presented in Table 31 in the appendix. The precipitation record is presented in Table 32 (appendix). Figures 1 and 2 show graphically the soil moisture fluctuations at various depths and the rainfall distribution during the period of this study.

The data in Tables 31 and 32 are used as a basis for most of

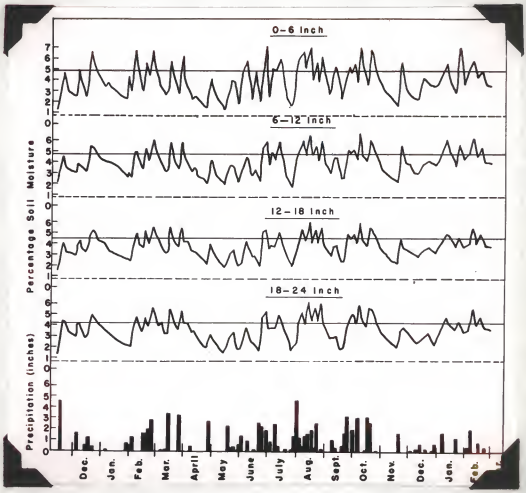


Figure 1.—Soil moisture fluctuations at four depths (0-24 inches) and precipitation from November 19, 1951 to February 28, 1953. Field capacity and permanent wilting percentage for different depths are represented by solid and broken lines.

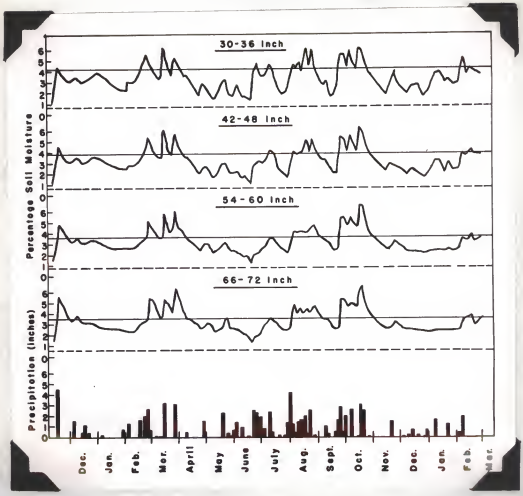


Figure 2.—Soil moisture fluctuations at four depths (30-72 inches) and precipitation from November 19, 1951 to February 28, 1953. Field capacity and permanent wilting percentage for different depths are represented by solid and broken lines.

the calculations throughout this study. Several general statements can be made at this point. A few of the more important ones are listed below:

1. The greatest gain and loss of moisture occurred in the 0-6 inches layer. This was expected because in addition to absorption by the roots, a considerable quantity was lost through evaporation. The moisture fluctuations became progressively less with each increasing depth.

2. Moisture was lost from the soil at a much faster rate during the summer months than during the winter months because of the high rates of transpiration and evaporation.

3. Whenever the soil moisture was above the field capacity, there was a rapid rate of moisture loss (representing loss of gravitational water) until the field capacity was reached. From field capacity the rate of moisture loss was fairly constant until approximately two-thirds of the available moisture was lost. The rate of moisture loss decreased from that point on. However, such decline was not observed in depths below that of 30-36 inches.

4. At no time during the entire experiment did the soil moisture content reach the permanent wilting percentage. However, on a number of occasions the soil moisture content dropped below one-third of the available moisture level. (This point will be discussed in more detail in the section of Transpiration)

3. <u>The distribution of feeder roots at different depths and their relation to moisture loss</u>.--In order to find out if there was any

correlation between distribution of feeder roots and moisture loss, beginning November 13, 1951, all soil samples were sieved through a No. 12 mesh screen (openings 0.065 inch or 1.6511 mm. in diameter) and roots were collected and weighed. The data presented in Table 1 represent a total of 2304 borings at each depth, from around 36 trees, between November 13, 1951 and February 27, 1953.

Table 1. The relation Between Feeder Root Distribution and Moisture Loss at Different Depths

Depth in Inches	Dry Weight of Roots	% Root Distribution	Percentage Water Loss
0- 6	1062.8 g.	21.0%	20.1%
6-12	663.0	13.1	13.5
12-18	512.3	10.3	9.8
18-24	592.1	11.7	9.4
30-36	566.9	11.2	8.5
42-48	321.4	6.4	7.0
54-60	144.8	3.0	4.5
66-72	78.5	1.6	3.7

Moisture loss at different depths was obtained from Table 31 (appendix) by using intervals when there was no precipitation and when the soil moisture content was below field capacity so that moisture loss through transpiration by trees and evaporation from ground surface were represented. Figure 3 illustrates diagrammatically the feeder root distribution and moisture loss.

Statistical analysis showed a highly significant correlation (r=0.813**) between the feeder roots distribution and percentage moisture loss. There is a sharp decline in the distribution of feeder roots beginning from the third foot to sixth foot. However, the decline

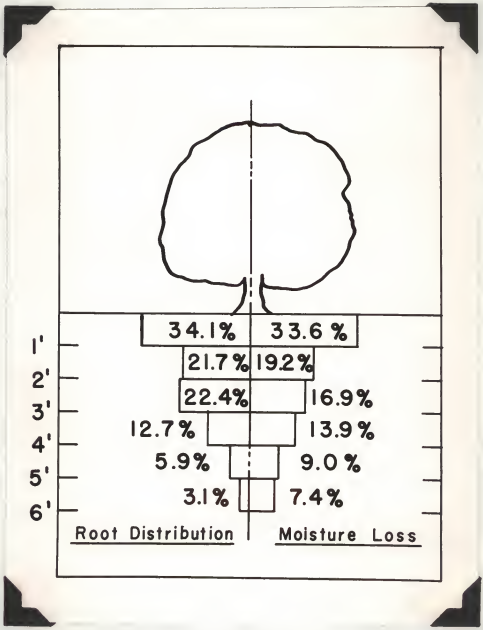


Figure 3.—The distribution of feeder roots of Marsh grapefruit trees in relation to moisture loss at different soil depths.

in the moisture loss at the same depths is somewhat more gradual. These results are in general agreement with findings by Ford (29).

4. Size of a representative sample.—Because of the wide variations observed in soil moisture percentage from one location to another throughout the entire experiment, it was decided to determine statistically the size of sample necessary in order to be representative. On February 12, 1953 a total of 36 samples were collected at each depth for 0-6, 6-12, 12-18, and 18-24 inches over an area of four and one-half acres in Block XIX. 18 samples were collected at each depth for 30-36, 42-48, 54-60, and 66-72 inches. The samples were collected in the same 6 plots and in a similar manner as in the soil moisture fluctuation study, except that all the trees were used. In other words, one sample was collected beyond the drip of each of the 36 trees, thus making 9 samples from each of the four directions. For samples collected from 36 to 72 inches, only 18 trees were used. The samples were made up of 5 borings each from north and east and 4 borings each from south and west. These data were analyzed by the formula given by Snedecor (91),

$$n = t^2 s^2 / (\bar{x}-m)^2$$

where s^2 is the variance, t represents the distribution of the parent population, $\bar{x}$ is the mean, and m is the deviation from the mean. The data are presented in Tables 33 and 34 (appendix). Table 2 shows the number of samples one should collect for different degrees of accuracy at various depths.

The greatest variations were found in the 0-6 inch depth. At

Table 2. Size of Sample Necessary to be Representative at Different Depths. (based on 4½ acres)

Depth in inches	Percentage deviation from mean 5%	10%	15%	20%
0- 6	156	39	17	10
6-12	46	11	5	3
12-18	23	6	2	1
18-24	66	17	7	4
30-36	77	19	8	5
42-48	74	19	8	5
54-60	105	26	12	7
66-72	92	23	10	6
0-72	80	20	9	5
6-72	69	17	7	4
6-48	57	14	6	4

this depth in order to be within 5% deviation from the mean it would be necessary to collect 156 randomly selected cores per 4½ acres; 39 cores would be necessary for 10% deviation; 17 cores for 15% deviation; 10 for 20% deviation, etc. From the practical standpoint soil moisture percentage at the 0-6 inch depth was relatively unimportant except where a study of evaporation was involved.

Based on this statistical analysis, the samples collected for soil moisture measurement in this thesis were accurate within 5 to 10 per cent of the mean. In other words, the number of samples collected each time for soil moisture determination was sufficient to assure values within a possible error of 5 to 10 per cent deviation from the mean.

B. Field Capacity

1. Determination of field capacity in the field.--On December 8, 1951 an area of 36 square feet was chosen between blocks XVIII and XIX for field capacity study. Trenches approximately 2 feet wide, were dug on all sides of a column of soil, and sheet metal was installed to a depth of 5½ feet to isolate the area from any root penetration by the adjacent trees. Water was applied through an open-top 55-gallon oil drum with holes of 1/8 inch in diameter and approximately 1 inch apart drilled at the bottom. It was hoped that the soil would be evenly saturated throughout with water in this manner, but the size of the holes was found to be too large and some difficulty was encountered. This was partly overcome by slowing down the rate of water flow into the drum and prolonging the time of application. Water was applied for approximately 2 hours. A piece of glass 36 inches square was used to cover the surface from which soil samples would be taken, to prevent excessive evaporation. On top of the whole area a heavy water-proofed canvas was used as an cover. Samples for soil moisture determination were taken at the following depths: 0-6, 6-12, 12-18, 18-24, 30-36, 42-48, 54-60, and 66-72 inches. Table 3 shows the moisture changes at different depths over a period of 35 days.

The data showed that in the 0-6 inch layer, field capacity was never reached as the term would be ordinarily defined. This indicated that evaporation was continuously taking place from that layer in spite of the glass cover. Field capacity at other depths was attained between the 6th and 8th day after the initial wetting. It is of interest to

Table 3. Results of Field Capacity Measurement at Various Depths Expressed as Percentage Soil Moisture

Days after wetting	Depth in inches 0-6	6-12	12-18	18-24	30-36	42-48	54-60	66-72
1	5.52	6.19	5.89	5.38	5.77	5.64	5.33	5.82
2	5.19	5.63	5.23	5.05	5.01	5.26	4.62	4.71
3	4.93	5.05	5.10	4.75	4.91	4.76	4.24	4.07
4	4.63	4.93	4.95	4.77	4.71	4.71	4.43	4.16
6	4.09	4.48	4.41	4.36	4.62	4.20	3.89	3.63
9	3.85	4.52	4.39	4.28	4.42	4.34	3.76	3.58
10	3.83	4.54	4.12	4.05	4.15	3.91	3.50	3.34
11	5.07	4.47	4.31	4.20	4.30	3.94	3.61	3.47
15	3.56	4.20	4.13	4.14	4.07	3.76	3.76	3.41
16	4.05	4.13	3.68	4.15	3.95	3.84	3.32	3.24
17	3.60	4.38	4.29	4.26	4.26	4.17	3.64	3.40
18	4.73	4.47	4.33	4.63	4.77	4.58	4.03	3.74
20	3.46	3.62	3.88	3.81	3.73	3.63	3.22	3.09
21	3.43	4.79	4.52	3.99	4.11	3.95	4.02	3.58
22	3.12	5.17	4.60	4.13	4.11	4.00	3.53	3.34
23	3.53	4.06	3.89	3.96	3.88	3.69	3.51	3.13
24	3.00	4.20	3.89	3.89	3.80	3.87	3.50	3.16
27	3.43	4.09	4.11	3.72	3.77	3.71	3.21	3.17
29	3.66	4.43	3.98	3.99	3.93	3.94	3.37	3.22
32	3.13	4.45	4.25	3.93	3.78	3.83	3.32	3.30
34	3.19	4.39	4.40	4.20	3.98	3.59	3.58	3.64
Field capacity*	3.60	4.34	4.16	4.08	4.08	3.92	3.58	3.38

*Taken from average of 6th day to 34th day.

note that the field capacity values became progressively less as the depths increased, presumably due to the differences in texture and organic matter contents.

On February 27, 1952 another study was conducted for the 0-6 inch depth. Immediately following a heavy rain of more than 3.5 inches, four 1-pound coffee cans coated with paraffin were buried inversely at

the ground level and covered with a thin layer of sand. The whole area was again covered by glass and canvas. Each can was only sampled once for soil moisture determination. The data are presented in Table 4.

Table 4. Field Capacity Study for 0-6 Inches

Period after wetting	Moisture content
2 hours	8.10%
5 days	4.86%
8 days	4.68%
13 days	4.77%
22 days	4.73%
Average from 5-22 days	4.76%

2. Measurement of field capacity by laboratory method.--A laboratory study of field capacity was also made. Shaw (89) showed that the addition of 6 inches of water to the surface of a column of dry soil 36 inches long resulted in a uniform moisture content to a depth of 24 inches and that the zone from 7 to 18 inches had a moisture content slightly higher than rest of the column after 123 days. Olmstead (67) irrigated soil columns 18 inches high and drained the excess water from them into dry soil beneath. He concluded that the average moisture content of the upper half of the drained soil column was a fair measure of its field capacity. The method used in this experiment was essentially the same as the one used by Olmstead.

The results of study of field capacity in the field indicated that the soil could be roughly classified into 3 zones: 0-12, 12-48, and 48-72 inches. The laboratory measurements of field capacity were made with soil sampled from these zones as follows:

2-liter graduate cylinders were filled to within about 2 inches of the top with air-dry soil, the soil being packed lightly as it was added to the cylinders. The amount of water necessary to raise the entire column of soil to the moisture equivalent was calculated and one-half of this amount was added to the top of the soil. The cylinders were covered loosely with rubber stoppers to prevent excess evaporation. They were set aside for approximately ten days and the percentage soil moisture was then measured with samples obtained from about the mid-section of the wetted column. A comparison of laboratory and field determinations of field capacity is presented in Table 5.

Table 5. A Comparison of Field Capacity Measurement by Laboratory and Field Method

Depths	Lab. Method	Field Method
0-12 inches	4.34%	4.55%
12-48 inches	4.22%	4.06%
48-72 inches	3.47%	3.48%

While the results of the two methods did not coincide exactly with each other, there was close agreement.

Beginning May 28, 1952, in connection with evaporation studies a series of four field capacity studies were made in different parts of the block. These studies were made at 6 inch intervals from 0-24 inches. (The procedure used is described in detail under "Evaporation".) The data are presented in Table 35 (appendix). Some of these values were found to be higher than the previous study. A number of factors may cause the variations, but the differences in the depth to clay layer

may at least account for some of the variations. The depth to clay layer in Block XIX varied from 5 feet at one end to 9 feet at the other. Replicates I and II were measured in areas with depths to clay of approximately 5½ feet and the values of field capacity were higher than that of the original study where the depth to clay layer was 9 feet. Replicates III and IV were measured in locations with depths to clay in excess of 8 feet. Consequently the field capacity values were similar to the values of the original study. The average of all five values was used in the calculation of percolation from 0-24 inches. The average values of field capacity for different depths are listed below:

0-6"	6-12"	12-18"	18-24"	30-36"	42-48"	54-60"	66-72"
4.85%	4.73%	4.33%	4.28%	4.08%	3.92%	3.58%	3.38%

3. Calculation of percolation.--Field capacity is defined as the maximum amount of water a soil can store. Whenever the moisture content of a given soil is above its field capacity, the excess gravitational water will be percolated away. Under field conditions percolation and absorption by tree roots takes place simultaneously. Table 3 gives the downward movement of water in an area where there is no root interference. Field capacity is obtained for most depths from six to eight days after wetting. The downward movement of water (Table 3) for the first ten days after wetting for each depth was plotted on common logarithm graph paper. The number of days when the soil moisture contents were above field capacity and actual moisture percentage of those days could be obtained from Figures 1 and 2 and Table 31 (appendix). The downward movement shown in Figures 1 and 2 represented both perco-

lation and uptake by roots. The field capacity curves show rate of downward movement due to percolation only. The difference in rate of downward movement between the two sets of curves is due to root absorption, and when these values are subtracted from the curves in Figures 1 and 2, the remainder is water moving by percolation.

An example of the calculation of soil water lost by percolation is presented in Table 6. The moisture contents for October 1 and October 4 were taken from Table 31 (appendix) and listed in columns one and two. The percentage moisture difference between the two dates represents "water loss". The number of days when the soil moisture remained above field capacity were obtained from Figures 1 and 2. When the moisture content (5.40%) of 0-6 inch depth was plotted against the curves of downward movement of moisture in absence of root interference (Table 3), it showed a moisture loss of 0.45% for one day. This quantity was considered to be percolated from that layer. Since the total moisture loss for the period was 1.75%, the difference of 1.30% was attributed to absorption by roots and evaporation. Percolation at the other depths was calculated accordingly.

The moisture gain or loss in the entire experiment was reported on the basis of gallons per tree. An acre of soil 6 inches deep weighs approximately 2,000,000 lbs. or 46 lbs. per square foot (2,000,000 lbs. per 43,560 sq. ft.). A 15-year old grapefruit tree on rough lemon rootstock occupies an area approximately 625 square feet. It weighs 625 x 46 = 28,750 lbs. of soil per tree to a depth of 6 inches. If there is 3% moisture in the 0-6 inch depth, there will be 28,750 x 3%

Table 6. Calculation of Percolation on Lakeland fine sand to a Depth of 6 Feet

Depth in inches	% Moisture Content 10/1/52	% Moisture Content 10/4/52	% Water Loss	Days Above Field Capacity	Percolation % Moisture	Percolation gal./tree	Root Absorption % Moisture	Root Absorption gal./tree
0- 6	5.40	3.65	1.75	1	0.45	15.5	1.30	44.8
6-12	5.18	4.17	1.01	1	0.21	7.2	0.80	27.6
12-18	4.87	3.97	0.90	2	0.29	10.0	0.61	21.0
18-24	5.06	4.10	0.96	2	0.29	10.0	0.67	23.1
24-36	5.45	4.32	1.13	3	0.73	50.3	0.60	11.4
36-48	5.11	4.28	0.83	3	0.59	40.7	0.24	16.6
48-60	5.30	4.62	0.68	3	0.60	41.4	0.08	5.5
60-72	5.19	4.61	0.58	3	0.53	36.5	0.05	3.4
Total			7.84%			202.1 gal.		183.4 gal.

= 862.5 lbs. of water. To convert pounds of water into gallons it is necessary to divide by 8.337 (1 gallon of water = 8.337 pounds). Therefore 3% moisture in a 6-inch layer will have 862.5/8.337= 103.45 gallons per tree. When a 12-inch layer is considered the weight of the soil per square foot is doubled (92 lbs.). As a result 3% moisture at 24-36 inch depth is equivalent to 206.9 gallons per tree.

The calculated quantity of percolation from November 19, 1951 to February 27, 1953 is presented in Table 7.

Table 7. Precipitation and Monthly Percolation on Lakeland fine sand (from November 19, 1951 to February 27, 1953)

Date	Percolation gal. per tree	Precipitation acre-inch	No. of rains more than 2.5"
11/19/51-12/27/51	278	2.77	1
12/17/51- 1/29/52	0	0.60	0
1/29/52- 2/27/52	471	5.87	1
2/27/52- 3/31/52	1746	6.47	2
3/31/52- 4/28/52	232	2.10	0
4/28/52- 5/31/52	0	3.08	0
5/31/52- 6/30/52	46	5.57	1
6/30/52- 8/ 2/52	166	5.63	1
8/ 2/52- 8/30/52	1621	9.30	3
8/30/52-10/ 1/52	469	6.47	1
10/ 1/52-11/ 3/52	2175	7.77	3
11/ 3/52- 12/1/52	0	1.33	0
12/ 1/52-12/29/52	0	0.90	0
12/29/52- 1/29/53	22	2.80	0
1/29/53- 2/27/53	48	3.17	0

These data indicate that the quantity of percolation was associated with the amount and intensity of precipitation. Whenever there was an accumulated rainfall of more than 2½ inches within a few days,

some percolation would occur depending on the soil moisture content before the rain. In August and October there were three times in each month when rains of more than 2½ inches occurred, and consequently the highest rates of percolation occurred in these two months. While August had the highest record of precipitation, there was actually more percolation in October than in August probably because of the higher mean temperature for August (80.8° F) than for October (73° F) and the consequent increased transpiration of the trees.

Not all the percolation could be calculated as previously described. There were three occasions (February 25-27, March 24-28 and September 27 to October 1, 1952) between November 19, 1951 and February 27, 1953, when percolation could not be calculated with the method employed. On all these occasions, a heavy rain which brought the soil moisture content above field capacity was followed by a second heavy rain within a few days so that the second rain could not be measured by the gain in soil moisture content. It was presumed that most of the second rain was percolated away. The question was then what portion of it was lost through percolation and what portion was absorbed by the tree roots. In such case the amount of tree absorption was arbitrarily ascertained by taking the average rate of transpiration several days before and after the rain. The remainder after evaporation had been deducted was considered as percolated. For example, the precipitation record (Table 32 appendix) shows that there was a rainfall of 3.23 acre-inches or 1,251 gallons per tree between September 23 and 25, 1952. Soil moisture samples taken on September 27 indicated a moisture per-

centage well above field capacity. This was followed by another rain of 1.66 acre-inches or 643 gallons per tree between September 27 and September 30. Soil moisture samples collected on October 1 indicated there was a gain of 0.15 inch or 55 gallons per tree. Calculation showed that the average rate of transpiration was 61 gallons per tree per day from September 20 to 24 and October 1 to 4. Therefore, it was presumed the tree absorbed 244 gallons (61 x 4 = 244) between September 27 and October 1. Percolation for the same period would be:

643-55-244-50 = 294 gallons per tree
(Percolation = rain-gain in soil moisture-tree consumption -evaporation)

C. The Permanent Wilting Percentage

The permanent wilting percentage is defined as the moisture percentage of the soil at the time the plant permanently wilts. The condition of permanent wilt is defined as that stage at which the leaves will not recover in a darkened saturated atmosphere without addition of water to the soil.

1. Method of measurement.—The permanent wilting percentage can be measured directly either in the field or in the laboratory. Field measurement is chiefly of value in regions with rainless seasons, whereby a system of regular soil sampling during the season can be obtained. When the curves of the soil moisture contents are plotted against time, the percentage at which the curve becomes nearly horizontal, indicating the extraction of moisture has nearly ceased, may be taken as the perma-

nent wilting percentage. Though the permanent wilting percentage obtained in this way is reasonably accurate and is reproducible in succeeding years, it has the disadvantage of being found comparatively late in the season. To determine whether the curve of moisture extraction is horizontal or nearly so, several points are necessary. In the meantime the plants must remain wilted and are likely to be injured by such periods of prolonged drought.

The laboratory methods are generally classified as physical and biological. The former utilizes the principle of soil moisture tension, since all plants wilt at about the same moisture potential (16×10^6 erg.). The latter consists of growing indicator plants in sealed containers until permanent wilting occurs. The biological method is probably more accurate and certainly the more widely used.

Sunflowers were selected in the present study as the indicator plants. Soils sampled from the following depths were used: 0-6, 6-12, 12-48, and 48-72 inches. Ten replications for each depth were used. The procedure used is described as follows:

About 600 grams of screened air-dry soil was placed in a waxed pint ice cream carton and three sunflower seeds were planted near the center of each carton. The cartons were then weighed and sufficient water added to bring the soil to the field capacity. After the seeds germinated, a healthy plant was selected and the other seedlings were removed. The containers were weighed daily and the moisture content maintained near field capacity by addition of tap water and occasionally of nutrient solution. Plants were allowed to grow until at least three

pairs of true leaves had developed. The containers were then sealed, the hole around the plant plugged with cotton, and the edges of the cover sealed with masking tape. Plants were then placed in the greenhouse and allowed to wilt. Wilting of one pair of leaves without recovery after 24 hours in a darkened moisture chamber was considered indicative of permanent wilting. After this stage was reached the soil moisture content was ascertained, the entire mass of soil in the container being used in moisture measurement.

2. Results.—The data are presented in Table 8 and the results of analysis of variance of the data are presented in Table 42 (appendix).

Table 8. Soil Moisture Content at Permanent Wilting Percentage at Different Depths on Lakeland Fine Sand

Depth in inches		0-6	6-12	12-48	48-72
Replications	1	0.69%	0.92%	0.70%	0.56%
	2	0.91	0.74	0.68	0.69
	3	0.74	0.93	0.64	0.68
	4	0.82	0.66	0.71	0.55
	5	0.79	0.77	0.75	0.59
	6	0.82	0.59	0.71	0.51
	7	0.77	0.86	0.68	0.61
	8	1.01	0.91	0.72	0.58
	9	0.80	0.81	0.70	0.60
	10	0.83	0.79	0.69	0.57
Mean		0.82%	0.80%	0.70%	0.60%

L.S.D.——1%:0.152 per cent 5%:0.113 per cent

Like field capacity the permanent wilting percentage decreased with increasing depth of soil. Wide variations were observed among the replicates within each depth, the greatest variations being found in the 0-6 inch and 6-12 inch depths. This was probably due to the more hetero-

geneous nature of the soil in the upper layers.

D. Readily Available Moisture

Readily available moisture is the capillary water in the range between the field capacity and the permanent wilting percentage. Gravitational water, while it is readily available to plants, seldom remains in the root zone long enough to be of much use to the plants. From the standpoint of growth and function of plants, this is the source of moisture of most practical importance. On Lakeland fine sand the quantity of the readily available moisture is rather limited, as is shown in Table 9.

Table 9. Range of Readily Available Moisture at Different Depths on Lakeland fine sand

Depth in inches	0-6	6-12	12-48	48-72
Field Capacity	4.85%	4.73%	4.13%	3.48%
Permanent Wilting	0.82%	0.80%	0.70%	0.60%
Readily Available Moisture	4.03%	3.93%	3.43%	2.88%

When the data in Table 9 are converted to gallons per tree or acre-inches, there are available at field capacity 1,659 gallons per tree or 4.28 acre-inches to a depth of six feet. Of this quantity 284 gallons per tree or 0.73 acre-inch is held by the soil particles at such a tension that for all practical purposes it is unavailable to plants, leaving a total readily available moisture content of 1,375 gallons per tree or 3.55 acre-inches to a depth of six feet.

Two questions of practical importance come to immediate atten-

tion: (1) how many days will 3.55 acre-inches of readily available soil moisture supply a citrus tree with adequate moisture; (2) can the tree extract this water with equal ease over the entire range. The first question will be discussed later after presentation of additional data. Observations from experiments in the field indicate that the readily available moisture was not equally available to the trees over the entire range. A check with Figures 1 and 2 indicates that when two-thirds of the readily available moisture had been used up there was a decrease in the rate of moisture loss. However, this phenomenon was not observed in layers below three feet, because soils at lower depths seldom reach that point. When the entire depth of six feet was considered, only on two occasions did the soil moisture drop to a point below one-third of the readily available moisture during the whole experiment. These conditions were reached on November 5, 1951 and again on May 9, 1952 (Table 31 appendix). The average daily moisture loss from October 22 to November 5, 1951 was 43.8 gallons per day with a mean temperature of 75.1° F for the same period. From November 5 to 13 the average daily loss was of 17.3 gallons a day with a mean temperature of 63.4° F. A 11.4° F decrease in temperature is equivalent to a drop of 16 gallons per tree per day in transpiration and evaporation losses. The actual decrease in average daily moisture loss was much greater, a drop of 26.5 gallons a day.

On May 9, 1951 two-thirds of the readily available water had been used up. The rate of moisture loss can be best illustrated in Table 10, which was computed from data in Table 31 (appendix).

Table 10. Average Daily Moisture Loss from Transpiration and Evaporation (April 28 to May 27, 1952)

Date	Average Daily Loss gal. per tree	Average Temperature
Apr.28-May 2,1952	39.4	71.8° F
May 2- 5	50.3	75.3
5- 9	54.7	79.0
9 12	5.8	80.3
19- 27	60.2	82.2

There was an increase of 10.9 gallons per tree in the daily moisture loss and 3.5° F in average temperature from May 2 to May 5, over April 28 to May 2. From May 5 to May 9, the increase in average temperature was 3.7° F but the increase in average daily moisture loss was only 4.3 gallons per tree. With less than one-third of the readily available moisture left in the soil, the average daily moisture loss dropped to 5.8 gallons per tree per day from May 9 to May 12 while the temperature remained high. The entire block was irrigated between May 13 and May 17. The average daily moisture loss regained its pace after irrigation as shown from May 19 to May 27.

Based on these data it is apparent that the readily available moisture is not equally available to the tree over the entire range. There is a decrease in the availability of this moisture after two-thirds of it has been removed. However, this reduction did not result in the appearance of wilting in the trees.

E. Evaporation

Evaporation of water from soils has been the subject of much

controversy for a long time. This is especially true from the point of view of practical significance of water losses by evaporation. Almost everyone is familiar with the fact that the soil dries out after a rain, at least in the surface layer. Moreover, it is recognized that this drying-out process depends upon weather conditions and the nature of the soil. A long debated matter has been the amount of water that evaporates from soils after the surface has become relatively dry.

Workers in climatology, ecology and forestry believe that meteorological factors such as temperature and relative humidity are the chief factors affecting evaporation. However, the work of Fisher (28), Keen (49), and others has proven that the degree of saturation with moisture is the most important soil factor affecting the amount of evaporation. Degree of saturation should perhaps be considered as of equal importance with meteorological factors. Much of the controversy may have been caused by the lack of satisfactory instruments for the measurement of evaporation. Atmometers have been extensively used in ecology and forestry for such measurement and Livingston (60) has contributed much toward the perfection of these instruments. However, evaporation from porous porcelain cups is essentially the same as evaporation from a free water surface. Preliminary observations with cans in connection with the present study indicated the rate of evaporation was not the same from a free water surface and soil, even though the latter was maintained at a high moisture content. Soils with a high moisture content may evaporate water at the same rate as that of a free water surface under similar conditions, but only for a very short period

of time. As soon as a dry crust is formed at the surface of the soil, the rate of evaporation of the two will not be the same. Hence, it was decided to study evaporation through soil moisture measurement.

1. Method of measurement.--Beginning November 19, 1951 an area of 900 square feet was chosen for evaporation study. The closest tree was approximately 90 feet away from this plot so there was little chance that roots would penetrate into the area. All vegetation inside the plot and in the immediate vicinity was removed. Samples were collected three times a week at 0-6, 6-12, 12-18 and 18-24 inch depths. Each sample was made up of 3 borings. To keep vegetation from reappearing in the plot the surface was hoed occasionally. These data are presented in Table 36 (appendix). Little or no evaporation could be found from layers below 6-12 inches. Beginning February 17 samples for moisture determination were collected at 0-6 and 6-12 inches only.

Some difficulty was encountered in the calculation of the quantity of evaporation, since after each rain there were a few days when evaporation could not be calculated because of the lack of knowledge concerning the rate of downward movement of water in the plot. Another question which arose during the study was whether the rate of evaporation in an open area was the same as that inside the grove. Since the relative humidity might be higher inside the grove because of transpiration from leaf surfaces, and since the shade offered by the trees would affect the soil temperature and indirectly affect the rate of evaporation, it was decided to study evaporation inside Block XIX.

Four 55-gallon oil drums with removable tops were obtained for

this study. The bottoms of these drums were cut off and the lower edges sharpened. These drums were approximately 33 inches in height. Each drum was driven into the ground until the top rim was about two inches above the surface of the soil. In order to minimize the disturbance of the soil inside the drum and to cut off the roots in the surrounding area, a trench was dug around the drum as it was being worked down. The trenches were refilled after the drums had been installed. These drums were located in different parts of the block, one being installed inside the canopy of a tree facing south and approximately two feet from the trunk while the others were installed approximately one foot beyond the leaf drip on the north, east and west sides of trees.

With the use of the drums the effect of root absorption was eliminated. The next step was to find out the rate of downward movement of water when the soil moisture content was above field capacity. On May 27, 1952 the soil contained in each drum was wetted with 50 gallons of water. The cover was put back on immediately after wetting and remained closed for 23 days, except when soil samples were collected. Samples were collected at depths of 0-6, 6-12, 12-18, and 18-24 inches. Field capacities inside the drums were reached between the sixth and eleventh day after wetting for most depths. These data are presented in Table 35 (appendix). The soil in each drum was again wetted with 50 gallons of water on June 25, 1952 and the drums remained closed for approximately for two weeks thus allowing the soil to attain field capacity. On July 9, 1952 covers were removed from all the drums. Beginning July 10 samples for moisture measurement were collected from

each drum separately. Depending on the pattern of rainfall, samples were collected daily or every other day. Due to the fact that the field capacities at different depths were not the same, after each sampling the hole was refilled with soils from the respective depths. To avoid sampling at the same location in short intervals, a sheet of cellophane with holes at two-inch intervals was used as a marker. In this manner samples could be collected at identical points from each drum at each time. In addition to the four drums, samples were also collected from the site of the original field capacity study. This site was on the south side of the tree, and was exposed to the sun practically all day long.

2. Calculation of evaporation.--When the soil moisture content was below field capacity, evaporational loss was calculated simply by taking the percentage moisture difference in Tables 37-41 (appendix) from day to day and converting it to gallons per tree. When the soil moisture content was above field capacity, calculation was similar to that of percolation. Instead of using the actual downward movement of moisture per unit time, the difference between the downward movement and the actual moisture content was used in the calculation of evaporational loss. For example, the soil moisture content for 0-6 inch on August 2, 1952 was 6.24% Table 37 (appendix). On August 4, 1952 the moisture content was 5.28% or a loss of 0.96% in two days. When it was plotted against downward movement curve of moisture for that particular drum and at that particular depth, it was found that downward movement was 0.74% in two days, leaving a difference 0.22%. Since the roots in these drums

had all been cut off, the difference must be due to evaporational loss. Similar calculations were made for the other three drums and the open site. The calculations were added together and divide by five to represent the average. The same manner was used for calculations for 6-12, 12-18, and 18-24 inch depths. The calculations showed that from August 2 to August 4, 1952, the average evaporational loss from 0-6 inch was 0.61%, 6-12 inch 0.12%, 12-18 inch 0.10%, and 18-24 inch 0%, making a total of 0.83% or 28 gallons per tree in two days.

Variations of soil moisture contents inside drums were observed. However, the effects of these variations were minimized by frequent sampling and calculations made on a day-to-day basis. One serious weakness of this method was that whenever a rain penetrated more than 24 inches deep, evaporational loss for that day could not be calculated. From July 10, 1952 to February 28, 1953 there was a total of forty-four days that evaporation could not be calculated, or one out of every five days. For those days the average daily evaporation for the month involved was substituted. Table 11 shows the evaporation from November 19, 1951 to February 28, 1953.

The data in Table 11 indicate that rate of evaporation was closely associated with the temperature and soil moisture content. Veihmeyer (96) showed that over a period of 80 days, 50 per cent of the evaporation occurred in the first week after irrigation and the other 50 per cent was lost over the remaining 73 days, a fact that further substantiates the influence of soil moisture contnet on the rate of evaporation. Statistical analysis showed that the multiple correlation

Table 11. The Relation of Evaporation to Temperature and Soil Moisture

Period of Time	Evaporation Loss per Tree(625 sq.ft.) Total	Daily Average	Monthly Mean Temperature	Available Soil Moisture to 24-inch Depth
11/19/51-12/27/51	154 gal.	4.4 gal.	62.5° F	3.06%
12/27/51- 1/29/52	97	2.9	64.4	2.36
1/29/52- 2/27/52	116	4.0	60.7	4.11
2/27/52- 3/31/52	258	7.8	67.9	3.29
3/31/52- 4/28/52	206	7.4	68.7	1.90
4/28/52- 5/31/52	356	10.8	77.6	2.04
5/31/52- 6/30/52	351	11.7	83.5	3.32
6/30/52- 8/ 2/52	304	9.2	82.8	3.39
8/ 2/52- 8/30/52	432	15.4	80.8	4.56
8/30/52-10/ 1/52	403	13.3	81.3	3.30
10/ 1/52-11/ 3/52	176	5.3	73.0	4.16
11/ 3/52-12/ 1/52	108	3.9	65.6	2.14
12/ 1/52-12/29/52	61	2.2	58.0	2.19
12/29/52- 1/29/53	176	5.7	60.5	3.45
1/29/53- 2/28/53	204	6.8	64.3	3.53

coefficient (R=0.710**) between evaporation, air temperature and percentage soil moisture was highly significant. The regression coefficients indicated that the average daily evaporation should increase 0.319 gallon per 625 square feet per day with an increase in each degree of the monthly mean temperature and increase 0.443 gallon per day with an increase of one per cent in the soil moisture content.

Table 12 shows the percentage of total evaporation with regard to depths and directions from July 10, 1952 to February 28, 1953.

Table 12. Percentage Loss of Water by Evaporation for Different Depths and Directions

Depth in inches	% Loss	Direction	% Loss
0- 6	75.3%	East	21.8%
6-12	19.6	West	23.2
12-18	3.4	North	9.0
18-24	1.6	South	29.9
		Inside Canopy	16.2

Approximately 75 per cent of the total evaporation occurred from the upper six inches. This represented about 40 per cent of the total moisture loss in that layer. Evaporation became insignificant below the 12-inch depth. Veihmeyer (96) reported in California that evaporation from a loam soil occurred chiefly in the top 4 inches and was negligible below 8 inches from the surface. Under the present study no evaporation was found for 12-18 and 18-24 inches during the winter months. Evaporation became noticeable at these two depths only when there was a rainless period of one week or longer.

There was considerable variations in evaporational loss on different sides of the trees. Nearly 30 per cent of the total evaporation occurred on the south side of the tree. This was expected because of its long exposure to the sun in the daytime. There was essentially no difference in evaporation between the east (21.8%) and the west (23.2%) sides. The lowest rate of evaporation (9.0%) occurred on the north side of the tree. It was of interest to note that evaporation inside the canopy of the tree (16.2%) was actually greater than on the north side. The fact that while the drum was located inside the canopy, it was on the south side of the trunk might account for part of this difference.

F. Transpiration by Trees

Transpiration by trees undoubtedly is the biggest single source of moisture loss from most soils. Veihmeyer (96) found that a 3-year-old prune tree in a tank used 585 pounds of water in 6 months, while a similar tank containing the same kind of soil with a high moisture content but uncropped, lost only 28 pounds of water over the same period. No attempt was made to measure the rate of transpiration directly in the present study since it involved too great an undertaking for mature trees. Even if direct measurements were made, their accuracy would be open to question.

The quantity of transpiration in the present study was obtained by subtracting the evaporation and percolation from the total water removed from the soil. Table 13 presents a summary of the different

Table 13. A Quantitative Estimate of Different Sources of Moisture Loss on Lakeland Fine Sand Planted with 15-year-old Marsh Grapefruit Trees. (Expressed in gallons per tree)

Date	Precipitation & Irrigation	Moisture Change*	Water Removed from Soil	Evaporation	Percolation	Transpiration per tree	Transpiration per tree per day
11/19/51-12/27/51	1073 gal.	L 430 gal.	1503 gal.	154 gal.	278 gal.	1071 gal.	28 gal.
12/27/51- 1/29/52	232	L 511	743	97	0	646	21
1/29/52- 2/27/52	2273	G1197	1076	116	471	490	16
2/27/52- 3/31/52	2506	L 316	2812	258	1746	818	26
3/31/52- 4/28/52	813	L 620	1433	206	232	995	36
4/28/52- 5/31/52	1193	L 296	1489	356	0	1133	34
5/31/52- 6/30/52	2157	G 255	1902	351	46	1551	53
6/30/52- 8/ 2/52	2336	G 192	2144	304	166	1674	52
8/ 2/52- 8/30/52	3602	G 415	3187	432	1620	1136	41
8/30/52-10/ 1/52	2506	G 335	2171	403	469	1299	41
10/ 1/52-11/ 3/52	3009	L 852	3862	176	2175	1511	46
11/ 3/52-12/ 1/52	515	L 145	660	108	0	551	20
12/ 1/52-12/29/52	349	L 230	579	61	0	518	19
12/29/52- 1/29/53	1084	G 233	831	176	22	653	21
1/29/53- 2/27/53	1228	G 313	915	204	48	663	22
Total	24877 gal.	L 79 gal.	25347 gal.	3357 gal.	7279 gal.	14706 gal.	
% Total Loss			100%	13%	29%	58%	

*Difference between the first and last day percentage moisture readings calculated as gallons of water for a given period. If there is a loss it is added to the precipitation and irrigation. If there is a gain it is subtracted from it.
G——gain L——loss

sources of moisture losses from which transpiration was calculated. The column under "Water Removed from Soil" was obtained by adding or subtracting the second column from the first column. Transpiration was obtained by subtracting evaporation and percolation from water removed from soil.

These data show wide variations in the quantity of water transpired in different months. The average daily transpiration for the whole year was 34.2 gallons per tree per day. However, the range varied from 16 gallons a day for the month of February, 1952 to 53 gallons a day for June, 1952. The increase or decrease in the rate of transpiration was closely correlated with the air temperature. The average daily transpiration, the mean monthly temperature, and the readily available soil moisture are presented in Table 14. Figure 4 shows the relationship between the average daily transpiration on a monthly basis and the mean monthly temperature and the readily available moisture in the soil. Temperature was the dominant factor in determining the rate of transpiration. In general, the correlation between transpiration and the readily available soil moisture was insignificant. The effects of the readily available soil moisture on the rate of transpiration became apparent at the lower range as shown in May, 1952. According to the mean monthly temperature, the daily rate of transpiration should have been approximately 70 gallons per tree per day, while the actual transpiration loss was only 34 gallons. Data in Table 14 indicate that although temperature is the dominant factor in determining the increase or decrease in the rate of transpiration, there are certain periods

Table 14. The Effects of Mean Monthly Temperature and Readily Available Soil Moisture on the Rate of Transpiration

Date	Mean Monthly Temperature	Ave. Available Moisture	Ave. Transpiration per tree per day
11/19/51-12/27/51	62.5° F	3.00%	28 gal.
12/27/51- 1/29/52	64.4	2.38	21
1/29/52- 2/27/52	60.7	2.92	16
2/27/52- 3/31/52	67.9	2.45	26
3/31/52- 4/28/52	68.7	2.60	36
4/28/52- 5/31/52	77.6	1.82	34
5/31/52- 6/30/52	83.5	1.98	53
6/30/52- 8/ 2/52	82.8	2.54	52
8/ 2/52- 8/30/52	80.8	2.83	41
8/30/52-10/ 1/52	81.3	2.91	41
10/ 1/52-11/ 3/52	73.0	4.06	46
11/ 3/52-12/ 1/52	65.6	2.25	20
12/ 1/52-12/29/52	58.0	1.85	19
12/29/52- 1/29/53	60.5	2.33	21
1/29/53- 2/27/53	64.3	2.95	22

during which the rate of transpiration cannot be explained by temperature differences. It is apparent there are other factors involved which have not been measured.

These observations were substantiated by statistical analysis. A highly significant correlation (r=0.834**) was found between the mean monthly temperature and the rate of transpiration. The regression coefficient was also significant at the one per cent level (t=5.522**). The relationship of the two was shown graphically in Figure 5. There was no significant correlation between the readily available moisture and rate of transpiration (r=0.062). However, when both variates are taken into consideration simultaneously the multiple correlation coefficient (R=0.835**) proved to be highly significant.

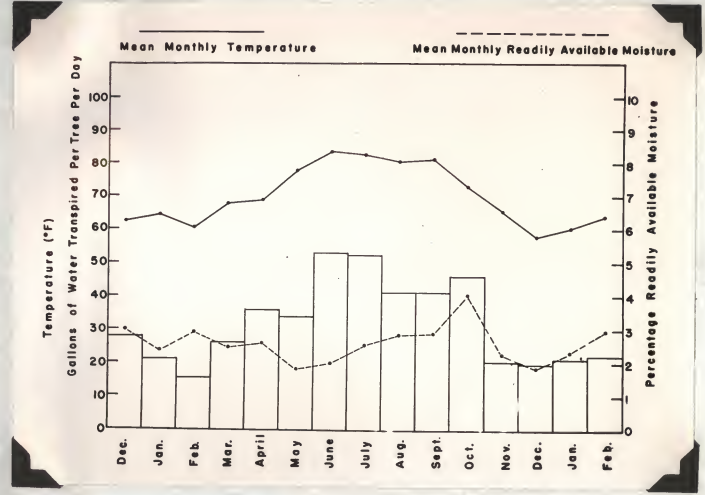


Figure 4.—The effects of mean monthly temperature and readily available soil moisture contents on the average daily rates of transpiration of Marsh grapefruit trees growing in Lakeland fine sand.

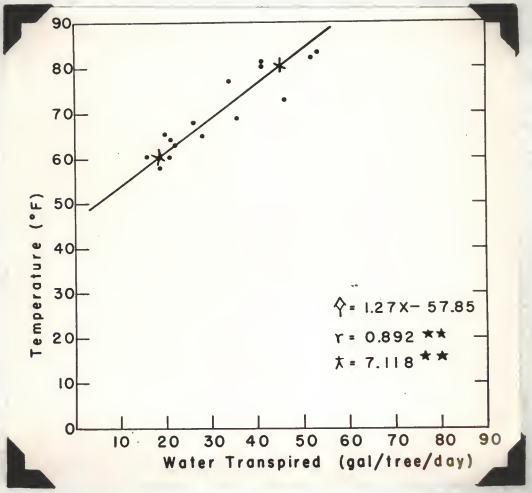


Figure 5.—Regression of mean monthly temperature on the rates of transpiration.

Cowles (20) studied the transpiration of Marsh grapefruit trees by the potometric method, using a small branch and estimating the total leaf area of the tree. His calculations showed that a Marsh grapefruit tree transpired 11 gallons of water a day, which was considerably less than the findings reported in this thesis. The accuracy of laboratory methods with cut branches when compared with trees in the field is often questionable. The results of certain irrigation investigations in California by Pillsbury, Compton and Picker (70) are presented in Table 15 together with the data reported in this thesis to serve as a comparison.

Table 15. A Comparison of the Average Daily Rate of Transpiration between Orange Trees in California and Grapefruit Trees in Florida

Month	California, 1928		Florida, 1952	
	Gal./tree	Mean Monthly Temp.	Gal./tree	Mean Monthly Temp.
January	12	51.6° F	21	64.4° F
February	14	55.0	16	60.7
March	10	54.0	26	67.0
April	17	55.8	36	68.7
May	24	60.7	34	77.6
June	35	63.2	53	83.5
July	39	69.8	52	82.8
August	38	69.5	41	80.8
September	34	66.5	41	81.3
October	22	63.4	46	73.0
November	17	62.0	20	65.6
December	14	52.2	19	58.0

While the data reported in California were considerably lower than those of Florida, the seasonal trends of the rate of transpiration

were very similar between the two. Several factors may contribute to these differences including the mean monthly temperature between the two states which is probably the most important factor. Other factors being equal, a 10°C rise in temperature results in doubling the rate of transpiration. The annual mean temperature for Orange County, California, in which the investigations were conducted, was 60.3°F for 1928 and the annual mean temperature at the Citrus Experiment Station, Lake Alfred, Florida for 1952 was 72.0°F, an equivalent difference of 6.7°C. Additional factors include differences in size of trees, the readily available soil moisture contents, rootstock, and distribution of rainfall in relation to mean temperature, all favor a higher rate of transpiration by trees under Florida conditions.

G. Discussion

Calculations in Table 13 showed that the biggest source of moisture removed from the soil was through the tree which accounted for 58 per cent of the total loss. Evaporation accounted for 13 per cent of the loss, and took place chiefly in the upper twelve inches of the soil. The quantity of water lost by percolation from the zero to six foot soil depth was unusually high. It represented 29 per cent or approximately one-third of the total loss. The high percentage of percolation can be explained by the limited storage capacity of the Lakeland fine sand in a region of comparatively high rainfall. It has a storage capacity of less than 4.30 acre-inches to a depth of six feet, of which only 3.50 acre-inches can be of any use to plants. The quantity of percolation is

chiefly determined by the amount and pattern of precipitation.

How long a given quantity of readily available moisture will adequately supply a citrus tree with water is a question of practical importance. No general statement can be made since there are tremendous variations between different times of the year. It is known, however, that both transpiration and evaporation are closely correlated to temperature. Therefore, it is possible to classify the moisture loss on the basis of mean temperature of any given period. It should be borne in mind that many other factors such as relative humidity, the intensity of solar radiation, the movement of air, the size of tree, the soil moisture content, etc., directly or indirectly influence the rates of transpiration and evaporation. Little information is available on how much influence each individual factor has, but together they have a profound influence on the rates of transpiration and evaporation. Temperature seems to have a more pronounced effect than any other single factor, however, and so it is used as a basis of classification here. Table 16 shows the rate of moisture loss at different times of the year under different temperatures.

Table 16. The Effects of Temperature on the Rates of Moisture Loss through Transpiration and Evaporation

Date	Moisture Loss	Average Daily Loss	Mean Temperature
Oct. 8-15, 1951	319 gal./tree	45.6 gal./tree	74.6° F
15-22	217	31.1	75.0
22-Nov. 2	506	36.1	75.1

Table 16—Continued

Date	Moisture Loss	Average Daily Loss	Mean Temperature
Nov. 5-13, 1951	138 gal./tree	17.3 gal./tree	63.4° F
19-Dec. 3	455	32.5	64.7
Dec. 3-17	497	35.5	66.0
17-27	289	28.9	65.0
Jan. 2-7, 1952	150	30.0	64.7
7-14	131	17.9	55.4
21-28	202	28.8	67.6
28-Feb. 5	275	34.3	59.6
Feb. 5-11	143	23.9	56.2
11-25	195	14.0	64.1
27-Mar. 10	426	35.5	64.0
Mar.15-24	283	31.5	68.6
Apr. 1- 7	285	40.6	70.0
10-24	644	46.0	76.3
28-May 9	529	48.1	76.4
May 19-27	469	58.6	82.2
June 5-11	458	76.4	82.5
11-14	196	65.3	82.7
14-20	429	71.5	84.5
27-July 7	728	72.8	84.7
July11-25	1018	72.7	82.2
25-Aug. 2	492	61.5	82.7
Aug. 6- 9	144	48.0	81.3
13-16	206	68.7	84.7
16-23	405	57.9	82.3
26-30	214	53.5	81.5
Sept.3-12	366	40.7	80.5
12-20	534	66.7	81.6
20-24	253	63.3	81.5
Oct. 1- 4	171	56.9	79.0
7-15	248	31.0	74.4
21-29	478	59.7	71.0
29-Nov. 12	465	35.8	67.8
Nov.12-21	260	28.9	67.6
21-Dec. 6	440	29.3	63.2
Dec. 6-10	82	20.6	60.0
10-15	35	7.0	54.6
15-29	287	20.5	56.7
29-Jan.10,1953	388	31.9	63.2
Jan.10-20	397	39.7	68.8
20-Feb. 4	215	14.3	57.6
Feb. 8-17	209	23.2	67.7
17-27	337	33.7	60.9

These data, with the exception of temperatures, were computed from Table 31 (appendix). The periods were chosen from intervals with less than 1.50 acre-inches of precipitation, thus eliminating some of the complication of percolation. Since percolation did not occur daily, it was best to remove that factor, but on occasions when percolation did occur, it was deducted. Therefore, the moisture loss represented only the transpiration and evaporation losses. Study of the data in Table 16 reveals that while different temperatures greatly affected the rate of moisture loss, other factors were also operative. However, until more is understood about the effects of the interaction of different factors, the influence of temperature will be used as a basis for classification. The average daily rates of moisture loss for different periods were classified into groups based on 5 degree Fahrenheit changes. (55-60, 60-65, 65-70, 70-75, 75-80, 80-85° F.) The average temperature and rate of moisture loss for each group are listed in Table 17, and plotted in Figure 6.

Table 17. Average Daily Temperature and Moisture Loss from Transpiration and Evaporation

Temperature	Moisture Loss gal./tree	acre-inches
57.6° F	21.9	0.06
63.7	27.7	0.08
66.9	31.9	0.10
73.0	41.7	0.11
77.6	49.1	0.13
82.4	63.0	0.16

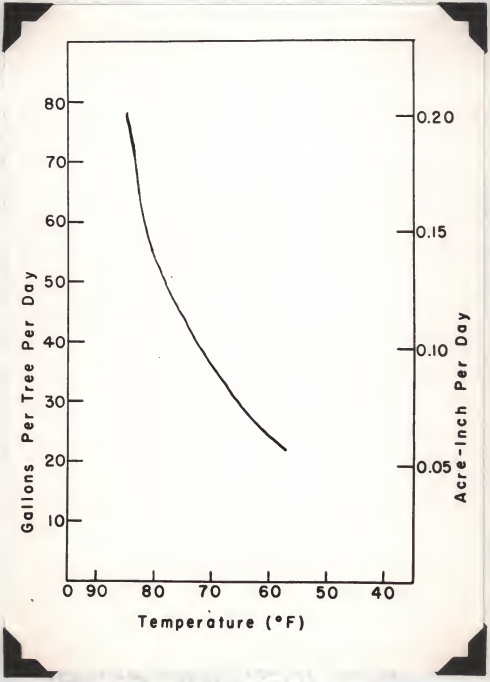


Figure 6.—The average daily evapo-transpiration losses at different temperatures.

The data showed that the daily rate of moisture loss varied directly with temperature. However, it was not a linear relationship, but a curvilinear one, as shown in Figure 6. It is possible to estimate the moisture loss for a given period of time from the curve if the temperature is known.

The total readily available moisture to a depth of six feet on Lakeland fine sand is 1,378 gallons per tree or 3.55 acre-inches. It has been shown that the rate of moisture loss is greatly reduced after more than two-thirds of the readily available moisture has been removed from the soil. Assuming that to be the critical point when the trees should be irrigated, it will leave in the moisture reservoir a total of 919 gallons per tree or 2.37 acre-inches that can be extracted by the tree with ease. Starting from the field capacity how many days can elapse before irrigation becomes necessary, assuming the average temperature of the period is 70° F? Figure 6 shows that at 70° F the rate of moisture loss was 35.5 gallons per tree or 0.09 acre-inch per day. At such a rate of loss there would be a period of approximately 26 days when there will be sufficient moisture in the soil. If the average temperature for the period is 80° F the same amount of water will be removed from the soil in less than 17 days. If the average temperature is 60° F the period of sufficient moisture can be stretched to 38 days.

This is in accordance with observations that during the winter months after a heavy rain the trees can withstand a period of three to four weeks of drought without suffering from moisture deficiency. It seems that the critical periods during the year are April-May and

October-November, just before and after the raining season when the average temperatures are relatively high and rainfall is frequently low. It should be emphasized that quantities expressed here may be useful for general consideration, but they are not to be applied without discrimination. Variations in individual groves such as age and size of trees, depth of soil to the hardpan, topography in relation to the surrounding area, and many other factors should be considered. It should also be emphasized that temperature, while very important, is only one of the many factors affecting the rates of transpiration and evaporation.

The results reported from this experiment are by no means exact. Probably the biggest source of error is in the variations in the soil moisture contents from one location to another. With the number of cores used in sampling an error of 5 to 10 per cent can be expected. There were also occasions when percolation and evaporation could not be calculated with the methods employed. Some error may have occurred in the estimation of these losses, although it is felt that the error involved is insignificant as compared with the inherent error of soil moisture variations. It is believed, however, that although the results reported in this experiment are by no means exact they give a reasonably correct picture of what is happening.

IV. THE EFFECTS OF VARYING SOIL MOISTURE CONTENTS ON THE RATE OF TRANSPIRATION OF CITRUS

The evidence that the rate of transpiration is affected by variations in soil moisture content within the range from field capacity to permanent wilting percentage is conflicting. Although the majority of the data published indicated that the rate of transpiration is not affected as long as the soil moisture content is above the permanent wilting range, results to the contrary have also been accumulating.

A. Study under Field Conditions

Most of the work has been done by growing plants in small containers and most of the opinions concerning the influence of moisture on transpiration have been obtained from them. Container experiments are valuable to indicate trends but certainly they should not be taken as being conclusive until verified by field trials. The hygroscopic-paper method was used to measure the rate of transpiration. While this method is not a quantitative measurement, it can be used to demonstrate the magnitude of the rate of transpiration. It was hoped that a comparison could be made between the irrigated and the non-irrigated trees. Bailey, et al. (4) studied the possibility of using the cobalt chloride technique to measure the absolute rates of transpiration, with a view of possible application of this method in field studies. They compared it with gravimetric water loss from small potted plants. Their results indicated that quantitative data could be obtained with the cobalt chloride procedure but these data showed no consistant relationship with

gravimetric observation.

1. Method and material.--The procedure used in this experiment was similar to the one described by Meyer and Anderson (66). Sheets of Whatman No. 50 filter paper were impregnated with a 3 per cent solution of cobalt chloride. The excess solution was removed with a rubber roller and the sheets were dried in an oven at 40° C. The drying was completed in a desiccator over anhydrous calcium chloride. The standardization of the cobalt chloride paper was accomplished by transferring sheets of known area to previously weighed weighing bottles, and determining the dry weight of the paper. The sheets of chloride paper were then spread in a humid chamber and turned with a pair of tweezer at intervals of about half a minute. As soon as any sheet just attained a pink color, it was transferred to a weighing bottle. A sheet of cobalt chloride paper had been placed in the humid chamber to serve as a standard. The sheets were reweighed when all had been thus transferred. The increment in weight represents the exact amount of water which has been absorbed by a known area of the paper in changing from blue to pink in color. The gain in weight was calculated per 100 square centimeter of paper.

$$G = \frac{3600X}{T}$$

G = water vapor loss in grams per sq. dm. per hour.
X = grams water required to change 1 dm. of cobalt chloride paper from blue to pink.
T = time.

Calculation of standardization of cobalt chloride paper is shown as follow:

Area of the filter paper = 0.7854 d^2
Diameter = 9 cm.
0.7854 d^2 = 63.62 square centimeters

	Weight		
Weighing bottle	57.5938g	53.4270g	58.8905g
Weighing bottle and dry filter paper	58.2113	54.0426	59.5043
Weighing bottle and moist filter paper	58.2528	54.0837	59.5455
Gain in weight	0.0415	0.0411	0.0412

Average gain in weight: 0.0413 gram

$$\frac{0.0413}{63.6174} = \frac{X}{100}$$

$$X = 0.064762 \text{ g./dm.}^2$$

$$G = \frac{3600 \times 0.064762}{\text{Time}}$$

Preparation of clips:---Specially designed metal clips were made at the Citrus Experiment Station for this purpose. Due to the high sensitivity of the cobalt chloride paper to the moisture vapor in the atmosphere, these clips were so designed that they could be clamped on the leaves with a fair degree of firmness. Cobalt chloride paper was cut into squares approximately one-half inch in diameter. They were placed on cellophane which had been cut to the size and shape of the clips and sealed with gum paper with holes in the center so that the cobalt chloride paper could come in contact with moisture vapor transpired from the leaves. The whole apparatus was then mounted onto the metal clip. Clips were kept in a tightly closed drying bottle until used.

Two trees were selected from each of the irrigation and non-irrigation plots. Preliminary observations indicated that there were variations in the rate of transpiration from leaves with respect to position on tree, on the branch and also within the same leaf. Leaves

that were exposed to the sun had a higher rate of transpiration than those in the shade. Only leaves on the south side of the trees were used for the study. Leaves close to the base of a twig had a higher rate of transpiration than those close to the tip. Therefore the leaves chosen were located midway between the base and the tip. It had also been observed that there was a higher rate of transpiration along the midrib than near the edge of the leaf, presumably due to higher concentration of stomates along the midrib. The portion of the leaf used to measure transpiration was 1½ inches back of the leaf tip and 2 mm. to one side of the midrib. Three leaves of approximately the same size and of the same flush of growth were used on each tree. Measurements were made between eleven and twelve o'clock in the morning. Temperature and relative humidity were recorded with a Friez Recorder. A Western Master II Universal Exposure Meter was used to measure the light intensity. The meter was held in front of the leaves and the light reflected from the leaf surface was recorded. The movement of air was arbitrarily classified as 1-still, 2-breeze, 3-moderate wind, and 4-strong wind. A stop watch was used to time the interval required for the hygroscopic paper to change from blue to pink. The clips were kept in desiccators at all time except when in use and the same clip was not used again in less than twenty-four hours. The rate of transpiration was expressed as grams of water vapor loss per square decimeter per hour. It was calculated by substituting the time (T) required for color change into the formula listed under "standardization of cobalt chloride paper".

2. Results.--Transpiration was measured at frequent intervals between November, 1951 and March, 1952. Data presented here include only days when the soil moisture contents were also determined. There was no irrigation applied during the winter of 1951 and 1952, and consequently, the soil moisture contents in the irrigation and the non-irrigation plots were essentially the same. The data reported under the columns of transpiration and soil moisture in Table 18 were taken from the average of the trees in both plots. Figure 7 is a graphic illustration of the data in Table 18.

Temperature was the most important factor affecting the rate of transpiration and the rate varied directly with fluctuations in temperature. In general, the rate of transpiration varied inversely with the relative humidity. However, frequently the effects of relative humidity were completely confounded by those of the temperature. No immediate effects of light intensity on the rate of transpiration were observed as long as it remained above 100 foot candles of reflected light. When it fell considerably below 100, the rate of transpiration was retarded as shown on March 3, 1952, which was cloudy. The effect of air movement if any was not observed, probably being completely overshadowed by other factors. There was no correlation between the rate of transpiration and the varying soil moisture contents which existed during the period in which this study was made.

Statistical analysis showed a significant correlation between temperature and the rate of transpiration ($r=0.525^{*}$). There was no significant correlation between other factors and the rate of transpira-

Table 18. The Effects of Environmental Factors on the Rate of Transpiration of Marsh Grapefruit Trees

Date	Transpiration	Soil Moisture	Temperature	Relative Humidity	Reflected Light Intensity	Air Movement*
Nov. 13, 1951	3.17 g./dm.^{2}/hr.	1.42%	69° F	54%	175 ft.candle	1
20	1.95	4.16	66	54	175	2
27	4.01	3.42	80	60	100	1
Dec. 3, 1952	4.68	2.70	82	67	125	4
10	5.28	3.38	80	50	175	2
Jan. 2, 1952	5.38	3.04	80	75	150	1
21	6.14	2.89	82	70	150	1
28	6.16	2.50	82	62	150	3
29	6.22	2.03	80	65	150	4
Feb. 2, 1952	7.41	2.98	80	65	180	3
5	6.16	3.39	70	70	165	4
11	8.48	3.15	82	45	175	2
14	6.73	3.85	74	70	150	2
28	8.06	5.53	76	45	200	2
Mar. 3, 1952	7.48	3.41	90	50	60	2
7	7.05	3.50	78	55	150	2
10	7.72	2.73	82	50	100	4
13	9.16	2.99	94	60	90	4

* 1---still
2---breeze
3---moderate wind
4---strong wind

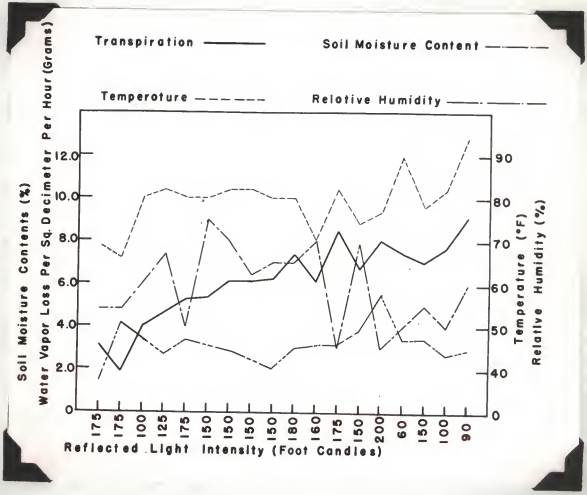

Transpiration
Soil Moisture Content
Temperoture
Relative Humidity
Soil Moisture Contents (%)
Water Vapor Loss Per Sq. Decimeter Per Hour (Grams)
Temperature (°F)
Relative Humidity (%)
Reflected Light Intensity (Foot Candles)
175 175 100 125 175 150 150 150 150 180 160 175 150 200 60 150 100 90

Figure 7.—The effect of environmental factors on the rate of transpiration of Marsh grapefruit trees.

tion ($r=0.183$ for soil moisture content, $r=-0.197$ for relative humidity, $r=0.027$ for light intensity, and $r=0.364$ for air movement). The efforts to study transpiration in the field with cobalt chloride paper were abandoned after March 10, 1952, as it was felt that the necessary information could not be obtained under the existing conditions.

B. Study under Laboratory Conditions

Failure to detect the effects of varying soil moisture contents if any, on the rate of transpiration in the field, because of lack of proper conditions for comparison, led to the decision to use container experiments and measure the rate of transpiration with gravimetric water loss.

1. Method and material.—Twenty, 1-year-old Cleopatra seedlings (*C. reticulata*), were selected for the study. The containers used were 5-quart oil cans. Each individual plant was weighed just before potting. The weights of the cans, metal covers, soil and water added were also taken. The quantity of soil and water were identical for all cans—6,000 grams of oven-dry soil and 420 grams of water. The soil and water for each container were completely mixed to insure even distribution of water by shaking vigorously in a closed container before the plant was potted. The plants were potted on June 20, 1952 and allowed to grow for approximately $5\frac{1}{2}$ months for the roots to be established in the soil. Moisture was maintained at the prescribed level (7%) by frequent weighing and nutrient solutions were added twice a month. The total leaf area of

each plant was measured just prior to the actual measurement of transpiration by tracing and cutting each individual leaf on paper of known size and weight. The plants were divided into 3 groups of 4 plants each and one group of 3 plants on the basis of similarity in the rates of transpiration when expressed in grams of water loss per square decimeter per 24 hours. The range between plants with the highest and lowest rates of transpiration within any one group was 3% for the group with most variations and 0.7% for the group with the least variation.

In order to measure whether different soil moisture contents affect the rates of transpiration or not, it is necessary to subject potted plants with different soil moisture contents to similar environmental conditions. It is impossible to maintain a predetermined moisture in the soil in which the plants were growing for any length of time. The procedure used in this experiment was to start one plant from each group at a point above field capacity and allow it to lose water through transpiration. Whenever one plant had reached a point of approximately two-thirds of the field capacity, a second plant in the same group was started above field capacity . The same procedure was applied to the third and fourth plant of each group. In this manner plants of different soil moisture contents were subjected to similar environmental conditions.

Experience with sandy soils has shown that the lack of uniformity in water penetration often resulted in very uneven distribution of water from one location to another. Leamer and Shaw (58) have designed an apparatus for measuring non-capillary porosity of soils. It was used in this experiment with slight modifications to approach uniform

moisture distribution throughout the container. The apparatus is described as follow:

The apparatus consisted of a sheet-metal base, in the center of which was soldered a ¼-inch gas pipe nipple. Over this base was a piece of fine plastic screen which was in turn covered by a layer of ordinary smooth desk blotter. To the nipple was connected a rubber tube which ran to a leveling bottle below the surface of the blotter. A continuous water column was established through the rubber tube from the surface of the blotter to the surface of the leveling bottle. The pores in the blotter were sufficiently small to prevent the menisci being broken at the tension used but still permit rapid water movement through the blotter. The tension was developed and controlled by regulating the pressure head between the level of the blotter and the surface of the level in the leveling bottle. Preliminary observations indicated that a tension equivalent to 70 centimeters of water column is the maximum that can be attained without breaking the menisci. With this tension an average difference of 0.2% existed between the moisture contents of the upper and lower halves of the soil in each container.

The plants were brought into the laboratory and the bottoms of the containers were removed with a large can opener. A piece of doubled muslin cloth was fastened to the bottom of the container to hold the soil in place. The container was then immersed in a tub of water, and the soil saturated. After saturation the container was set on a blotter for approximately 30 hours to permit excess water to be drawn off. Preliminary observations indicated that with the size of container

and the amount of soil used, this time was sufficient to lower the water content to a point approximately one-half per cent above the field capacity. Little additional water was removed from the container when allowed to set longer than 30 hours. After the excess water had been removed, the bottom was put back on again and sealed with masking tape. The plants were set on a platform in the open facing south. Plants were weighed daily and the moisture loss recorded. The percentage of soil moisture was calculated accordingly. In the end soil samples were collected from the containers and the moisture was measured by the oven-dry method to serve as a check.

2. Results.--Due to an unforseen accident in the laboratory, two plants from Replications II and III were exposed to ammonium hydroxide and lost over 50 per cent of their leaves. These plants were discarded, leaving three plants each in Replications II and III. The data are presented in Tables 19,20, 21 and 22. Figures 8,9,10 and 11 show graphic comparisons of the magnitudes of transpiration for plants at different soil moisture contents. The plant with the highest range of soil moisture content was considered to have a transpiration rate of one and the rates of transpiration of other plants in comparison were expressed in percentage of that one. For example, a comparison of plants 1 and 2 in Replication I showed that the rate of transpiration for plant 1 was 66% that of plant 2, while the range of soil moisture contents was 2.50-2.00% for the former and 5.57-4.97% for the latter for the same period.

There was one factor overlooked in grouping the plants into replications. The classification was based on the rates of transpiration

Table 19. Rates of Transpiration for Plants under Different Soil Moisture Contents (Replication I)

Date	Plant #1 Transpiration*	Plant #1 Soil Moisture	Plant #2 Transpiration*	Plant #2 Soil Moisture	Plant #3 Transpiration*	Plant #3 Soil Moisture	Plant #4 Transpiration*	Plant #4 Soil Moisture
12/29/52	2.03g	2.50%	2.31g	5.57%				
30	0.81	2.43	0.91	5.48				
31	1.01	2.35	1.85	5.35				
1/ 1/53	2.63	2.13	2.54	5.17				
2	0.40	2.10**	2.78	4.97				
3	1.82	1.95	2.31	4.80				
5	0.71	1.83	2.54	4.63				
6	0.81	1.77	1.62	4.50	1.67g	5.53%		
7	1.22	1.67	2.08	4.32	2.77	5.25		
8	2.03	1.48	3.93	4.03	3.64	4.87		
9	0.20	1.47	0.69	3.98	0.69	4.83		
10	0.41	1.45	0.91	3.92	0.72	4.80		
11	0.41	1.43	1.62	3.80	1.98	4.58		
12	0.62	1.38	1.85	3.67	2.16	4.38		
13	1.01	1.30	2.78	3.47	3.59	4.05		
14			0.95	3.40	1.08	3.95		
15			2.62	3.22	2.70	3.70	2.83g	5.33%
16			1.91	3.08	3.41	3.38	2.90	5.17
17			1.43	2.98	1.98	3.20	2.19	5.00
19			2.26	2.67	2.16	2.80	3.04	4.65
20			0.95	2.60	1.26	2.68	2.03	4.53
21			3.10	2.38	2.62	2.45	4.63	4.26
23			1.31	2.16	1.40	2.20	3.04	3.92
24			1.43	2.10	2.06	2.02**	3.34	3.70
27			1.35	1.82**	0.97	1.78	1.80	3.35
28			0.95	1.75	1.45	1.67	2.57	3.18
30			1.19	1.58	0.94	1.52	2.31	2.88
31			0.71	1.53	0.42	1.48	3.34	2.83
2/ 2/53			0.42	1.43			2.18	2.55
Soil Moisture (oven-dry)		1.36%		1.36%		1.54%		2.48%

* Transpiration expressed in grams per square decimeter per 24 hours.
** Beginning to show signs of wilt.

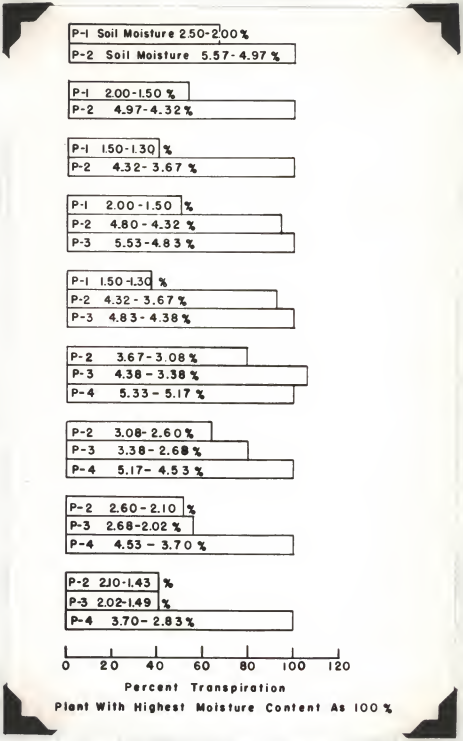


Figure 8.—Comparisons of rates of transpiration of plants with different soil moisture contents grown under similar environmental conditions. (The same number of days were involved within each comparison.) (Replication I)

Table 20. Rates of Transpiration for Plants under Different Soil Moisture Contents (Replication II)

Date	Plant #5		Plant #6		Plant #7	
	Transpiration*	Soil Moisture	Transpiration*	Soil Moisture	Transpiration*	Soil Moisture
1/ 1/53	2.17g	2.50%	1.83g	7.08%		
2	2.39	2.32	3.26	6.82		
3	0.43	2.28	2.64	6.60		
4	0.98	2.13	3.26	6.33		
5	0.22	2.12	1.83	6.18		
7	0.55	2.03**	1.63	5.96	1.52g	5.83%
8	3.26	1.78	5.09	5.50	4.57	5.48
9	0.40	1.75	0.41	5.47	0.22	5.47
10	0.78	1.72	0.61	5.42	0.43	5.43
11	1.18	1.65	1.83	5.27	1.52	5.32
12	0.59	1.62	2.24	5.08	1.54	5.20
13	1.77	1.52	4.27	4.73	4.97	4.90
14	0.59	1.48	0.97	4.65	0.20	4.89
15	1.77	1.38	2.90	4.40	3.00	4.67
16			3.10	4.13	2.51	4.48
17			4.84	3.73	2.29	4.32
19			2.03	3.37	2.40	3.97
20			1.74	3.22	1.37	3.87
21			3.68	2.90	3.89	3.58
23			2.37	2.52	1.90	3.28
24			3.50	2.23	2.97	3.07
27			1.30	1.92	1.30	2.78
28			1.23	1.82	2.51	2.60
30			1.64	1.55**	2.17	2.28
31			0.62	1.50	1.83	2.15
2/ 2/53			1.13	1.32	1.83	1.88**
Soil Moisture (oven-dry)		1.50%		1.29%		2.01%

* Transpiration expressed in grams per square decimeter per 24 hours.
** Beginning to show signs of wilt.

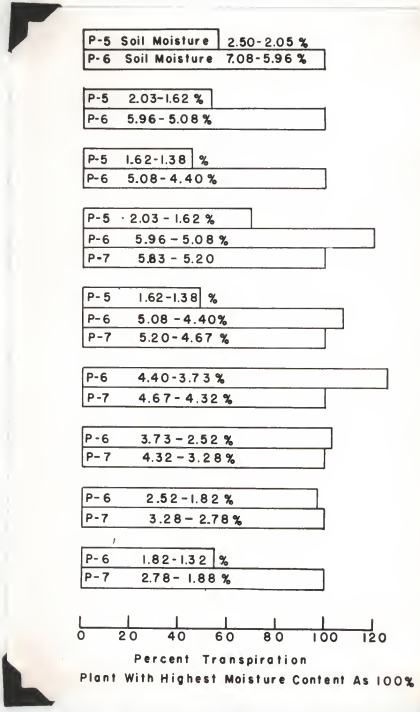


Figure 9.--Comparisons of rates of transpiration of plants with different soil moisture contents grown under similar environmental conditions. (The same number of days were involved within each comparison.) (Replication II)

Table 21. Rates of Transpiration for Plants under Different Soil Moisture Contents (Replication III)

Date	Plant #8		Plant #9		Plant #10	
	Transpiration*	Soil Moisture	Transpiration*	Soil Moisture	Transpiration*	Soil Moisture
1/ 7/53	3.24g	2.82%	0.87g	5.93%		
8	2.15	2.53	5.73	5.38		
9	0.60	2.50	0.50	5.33		
10	0.90	2.45	0.18	5.32		
11	0.90	2.40	1.07	5.22		
12	0.90	2.35	1.60	5.07		
13	2.39	2.22	3.15	4.78		
14	0.60	2.18	0.74	4.72		
15	1.20	2.12**	2.41	4.50		
16	2.09	2.00	1.67	4.35	2.62g	7.07%
17	0.90	1.95	2.96	4.08	3.41	6.85
19	1.62	1.80	2.50	3.63	2.41	6.58
20			1.48	3.50	2.70	6.43
21			2.96	3.23	3.31	6.25
23			2.03	2.85	3.46	5.87
24			2.88	2.60	3.91	5.65
27			1.03	2.30	2.20	5.28
28			0.86	2.22	3.31	5.10
30			1.59	1.93**	3.16	4.75
31			0.36	1.90	3.91	4.53
2/ 2/53			0.93	1.73	2.71	4.23
6			1.21	1.33	2.55	3.67
Soil Moisture (oven-dry)		2.02%		0.96%		3.73%

* Transpiration expressed in grams per square decimeter per 24 hours.
** Beginning to show signs of wilt.

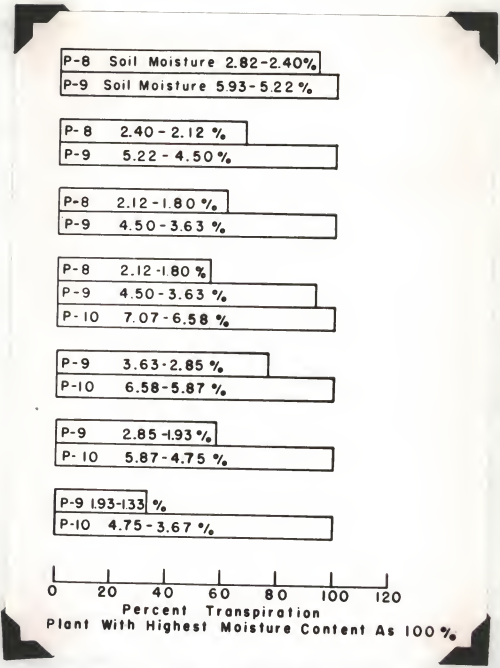


Figure 10.--Comparison of rates of transpiration of plants with different soil moisture contents grown under similar environmental conditions. (The same number of days were involved within each comparison.) (Replication III)

Table 22. Rates of Transpiration for Plants under Different Soil Moisture Contents (Replication IV)

Date	Plant #11		Plant #12		Plant #13	
	Transpiration*	Soil Moisture	Transpiration*	Soil Moisture	Transpiration*	Soil Moisture
1/ 7/53	2.21g	2.55%	2.24g	5.38%		
8	2.21	2.40	2.98	5.18		
9	0.49	2.37	1.24	5.10		
10	0.24	2.35	0.50	5.07		
11	1.47	2.25	0.50	5.03	0.42g	6.10%
12	0.98	2.18	1.24	4.95	1.66	5.97
13	1.47	2.08	2.48	4.78	2.29	5.78
14	0.74	2.03	0.74	4.73	0.42	5.75
15	1.23	1.95**	3.48	4.57	2.31	5.57
16	1.72	1.83	1.99	4.43	3.16	5.32
17	0.74	1.78	1.99	4.30	1.26	5.22
19	0.74	1.68	1.74	4.07	2.29	4.88
20			1.24	3.98	2.06	4.73
21			1.74	3.87	1.83	4.60
23			2.86	3.48	2.63	4.22
24			3.48	3.25	2.74	4.02
27			1.38	2.93	1.37	3.72
28			1.52	2.82	1.83	3.58
30			1.63	2.57**	2.85	3.18
31			0.44	2.53	1.19	3.10
2/ 2/53			1.31	2.33	1.78	2.85
6			1.35	1.90	1.66	2.38
7			0.41	1.87	1.90	2.25
9			0.31	1.82	0.60	2.17
Soil Moisture (oven-dry)		1.62%		2.02%		2.25%

* Transpiration expressed in grams per square decimeter per 24 hours.
** Beginning to show signs of wilt.

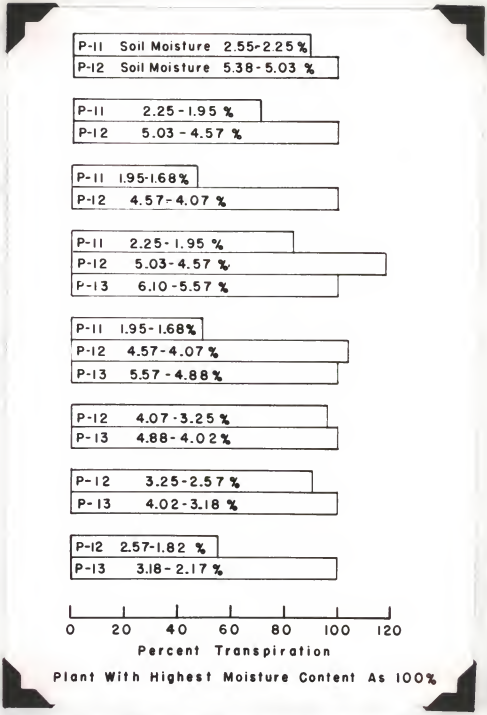


Figure 11.—Comparison of rates of transpiration of plants with different soil moisture contents grown under similar environmental conditions. (The same number of days were involved within each comparison.) (Replication IV)

per square decimeter per 24-hour period but not on total transpiration. Therefore a plant with more leaf surface would lose more water than one with less leaf surface, although the rates of transpiration of the two per unit of leaf area were similar. This became evident in plant 3 in Replication I. Plant 3 was started on January 5, 1953 at a calculated soil moisture content of 5.53%. The soil moisture content for plant 2 on the same day was 4.50% or approximately 1% lower than that of plant 3. The soil moisture content of plant 2 on January 31 was 1.53% while that of plant 3 was 1.48%, indicating that plant 3 had transpired considerably more water than plant 2.

Most of the plants began to show signs of wilt when the soil moisture contents were reduced to about 2.00%, although the range varied from 1.57 to 2.55%. This was probably due to the fact that some plants have better roots than the others.

Figures 12 and 13 show photographic comparisons of plants at different soil moisture contents. There was no difference in appearance for plants at soil moisture contents of 3.67%, 4.38% and 5.77%. The plant with 1.38% moisture has leaves curled and drooped.

A purple mite infestation which was noticed on the plants during the course of the experiment caused leaf drop to several plants, especially during the latter part of the experiment when the soil moisture contents were low. The following plants lost over 10 per cent of their leaves: plant 3 in Replication I (12%), plant 10 in Replication II (11%), plant 13 in Replication IV (11½%). The number of leaves on each plant was counted once a week and adjustments were made in the total leaf surface according to the number of leaves dropped. It is possible

Figure 12.—Plants of different soil moisture contents within one replication.

Figure 13.--A comparison of plants with the highest and lowest soil moisture contents in one replication.

that some error may have been encountered in making such adjustments, since no two leaves will transpire exactly the same.

Soil moisture determinations by the oven-dry method were in general agreement with the calculated moisture contents. This experiment was discontinued on February 9, 1953 because the plants put out a new flush of growth at that time.

The experiment was resumed in April, 1953 following a new flush of growth. The total leaf area of each plant was again measured and the plants were reclassified into 3 groups of 3 plants each on the basis of similar rates of transpiration when expressed in grams of water loss per square decimeter per 24 hours. The other procedures used were similar to those described for the previous experiment. As in the previous study, the rates of transpiration of plants with different soil moisture contents were compared. The plant with the highest soil moisture content in each comparison was considered to have a rate of transpiration of 100% and the rates of transpiration of other plants were expressed as percentages of that plant. The fresh weight of each plant was measured at the end of the experiment. The increase in weight when compared with the weight at the time of potting varied from 6 to 18 grams. Since the soil moisture is the only variate in this experiment, any increase in the weight of plant directly affects the calculation of soil moisture percentage. Therefore the soil moisture content values have been adjusted according to the weight increment of each plant. The data are presented in Tables 23,24 and 25.

These results are very similar to the previous study. The rate

Table 23. A Comparison of Rates of Transpiration of Plants Growing in Soil of Different Moisture Contents (Replication I)

	Plant #1				Plant #2			Plant #3	
Date	Transpiration*	Soil Moisture Content	% Transpiration of Plant #2	% Transpiration of Plant #3**	Transpiration*	Soil Moisture Content	% Transpiration of Plant #3**	Transpiration*	Soil Moisture Content
4/8/53	6.07g.	5.28%							
9	8.29	4.38							
10	6.91	3.63							
11	5.68	3.02	81%		6.99g.	7.18%			
14	4.15	2.63	76	80%	5.49	6.63	106%	5.20g.	7.60%
15	1.69	2.45	21	22	8.15	5.82	105	7.74	6.90
17	2.76	2.15***	38	33	7.31	5.08	87	8.35	6.15
18	2.30	1.90	25	27	9.31	4.15	109	9.54	5.38
19	2.61	1.62	42	37	6.16	3.53	87	7.05	4.75
20	1.23	1.48	28	37	4.33	3.10	58	7.42	4.08
23					2.87	2.23	80	3.53	3.15
25					3.83	1.85	54	7.05	2.50
26					2.00	1.65***	83	2.41	2.28
27					1.66	1.48	74	2.23	2.08***
Soil Moisture (oven-dry)		1.55%				1.47%			2.15%

* Transpiration expressed in grams per square decimeter per 24 hours.
** Plants with higher soil moisture content are considered as 100%.
*** Beginning to show signs of wilt.

Table 24. A Comparison of Rates of Transpiration of Plants Growing in Soil of Different Moisture Contents (Replication II)

Date	Plant #4 Transpiration*	Plant #4 Soil Moisture Content	% Transpiration of Plant #5	% Transpiration of Plant #6**	Plant #5 Transpiration*	Plant #5 Soil Moisture Content	% Transpiration of Plant #6**	Plant #6 Transpiration*	Plant #6 Soil Moisture Content
4/2/53	8.11g.	5.15%							
3	5.12	4.69							
4	6.53	4.06							
5	7.06	3.40	101%		6.99g.	6.48%			
6	6.17	2.81	94		6.55	5.78			
8	5.47	2.30	63		8.65	5.12			
9	1.59	2.15***	19		8.48	4.27			
10	2.82	1.88	37	35%	7.65	3.50	94%	8.16g.	7.20%
11	2.82	1.61	43	36	6.49	2.85	82	7.89	6.28
14	1.06	1.53	49	31	2.16	2.63	63	3.44	5.88
15	1.51	1.38	40	18	3.82	2.25	45	8.46	4.90
17	1.76	1.21	66	20	2.66	1.98	31	8.60	3.90
18	1.76	1.05	71	29	2.49	1.73***	42	5.88	3.21
19	1.59	0.90	80	38	2.00	1.53	48	4.16	2.73
20					1.00	1.43	50	2.01	2.50
23					2.66	1.17	66	4.01	2.03
25					1.66	1.00	50	3.30	1.67***
26								1.72	1.45
27								1.43	1.38
Soil Moisture (oven-dry)		0.73%				1.18%			1.60%

* Transpiration expressed in grams per square decimeter per 24 hours.
** Plants with higher soil moisture content are considered as 100%.
*** Beginning to show signs of wilt.

Table 25. A Comparison of Rates of Transpiration of Plants Growing in Soil of Different Moisture Contents (Replication III)

Date	Plant #7 Transpiration*	Plant #7 Soil Moisture Content	Plant #7 % Transpiration of Plant #8	Plant #7 % Transpiration of Plant #9**	Plant #8 Transpiration*	Plant #8 Soil Moisture Content	Plant #8 % Transpiration of Plant #9**	Plant #9 Transpiration*	Plant #9 Soil Moisture Content
4/4/53	4.97g.	5.99%							
5	5.99	5.20							
6	6.62	4.50							
8	4.71	3.89							
9	4.33	3.32	90%		4.81g.	5.09%			
10	4.20	2.77	72		5.87	4.44			
11	2.80	2.49	42		6.62	3.70			
14	1.91	2.40***	49	52%	3.91	3.27	106%	3.70g.	7.75%
15	1.15	2.12	42	124	2.71	3.15	291	0.93	7.67
17	2.61	1.97	60	44	4.36	2.49	74	5.92	7.04
18	2.76	1.67	122	45	2.26	2.23***	37	6.11	6.58
19	1.91	1.42	85	36	2.26	1.99	42	5.37	6.10
20	1.78	1.18	108	36	1.65	1.80	33	5.00	5.65
23	1.20	1.05	38	13	3.16	1.45	35	9.07	4.84
25	1.65	0.83	58	19	2.82	1.19	32	8.89	4.04
26					1.41	1.05	36	3.89	3.85
27					1.59	0.90	45	3.66	3.53
Soil Moisture (oven-dry)		0.87%				0.81%			3.54%

* Transpiration expressed in grams per square decimeter per 24 hours.
** Plants with higher soil moisture content are considered as 100%.
*** Beginning to show signs of wilt.

of transpiration decreases as the soil moisture content decreases. This reduction in the rate of transpiration becomes apparent when more than half of the readily available moisture has been lost. Most of the plants began to show signs of wilt when the soil moisture contents were reduced to about 2.00% with the range varied from 1.65 to 2.40%. (The range was 1.57 to 2.55% in the previous study) In general, the rate and total transpiration were higher than the first study because of the higher daily temperature and the increased total leaf area of the plants.

In an attempt to find out if the soil was drying out uniformly throughout the container, each can was divided into 8 sections; 4 sections, 90 degrees apart represented the upper half of the soil column and 4 sections represented the lower half. Samples were collected from these sections and moisture determinations were made. The data are presented in Table 26.

With the exception of plant No. 9, which was still amply supplied with water at the end of the experiment, the soil in all cans was found to contain less soil moisture in the lower half of the container. It was also noted that the moisture content in the lower half was much more uniform than that in the upper half because of greater concentration and more uniform distribution of roots in the lower half. The wide variations in soil moisture content observed in the soil in the upper half of the container can be explained, in part as resulting from moisture condensation on the metal cover. How extensively this occurred is unknown.

Table 26. Variations in Soil Moisture Contents as Affected by Position of Soil in the Container (Expressed in Percentage Dry Weight)

Plant	Upper Half					Lower Half					Average for Container
	1	2	3	4	Average	1	2	3	4	Average	
1	1.57	2.05	1.86	1.97	1.86	1.19	1.16	1.27	1.32	1.24	1.55
2	1.53	1.98	1.66	1.53	1.68	1.24	1.08	1.33	1.37	1.25	1.47
3	2.79	2.18	2.18	2.78	2.48	1.96	1.78	1.77	1.79	1.83	2.15
4	0.93	0.89	0.96	0.70	0.83	0.80	0.77	0.83	0.76	0.79	0.73
5	1.04	2.45	0.95	0.93	1.34	0.88	1.07	1.11	1.02	1.02	1.18
6	1.42	2.21	2.24	1.90	1.94	1.11	1.16	1.50	1.30	1.27	1.60
7	1.06	0.60	0.89	1.07	0.90	0.87	0.79	0.86	0.79	0.83	0.87
8	1.28	0.97	0.58	1.12	0.94	0.86	0.80	0.72	0.35	0.68	0.81
9	3.11	3.42	2.93	3.18	3.16	4.29	3.64	3.95	3.85	3.93	3.54

C. Discussion

Results from these experiments showed that moisture was not equally available to plants between the field capacity and the permanent wilting percentage. The plants showed a gradual decrease in the rate of transpiration when more than half of the readily available moisture had been lost. This decrease, however, was not very apparent until the soil moisture content has reached the remaining one-third of the readily available moisture. With more than two-thirds of the readily available moisture removed from the soil, the rates of transpiration showed a sharp drop. In terms of soil moisture content, the point of one-third readily available moisture was around 2.15%. While there were variations with individual plants, there was a rather distinct decline in the rate of transpiration beyond that point of one-third readily available moisture. Most of plants began to show signs of wilt when the soil moisture content was reduced to approximately 2.00%, a point just beyond the mark of one-third of the readily available soil moisture. Plants showed severe signs of wilt when the soil moisture content was reduced to about one-half per cent above the permanent wilting percentage.

The results from these experiments were further substantiated by soil moisture studies in the field. From the practical standpoint the fact that water was not equally available to plants between the field capacity and the permanent wilting percentage would certainly be worthy of consideration in planning and timing of irrigation.

V. THE TENSIOMETER AS A MEANS OF MEASURING SOIL MOISTURE

The soil moisture tensiometer has been used to measure soil moisture under laboratory, greenhouse and field conditions, and to study its movement, penetration and extraction by roots. The chief purpose of this experiment was to test the practical application of the tensiometer as an indicator of when to irrigate.

A. Method and Material

The tensiometric method of measuring soil water involves the use of a mercury manometer to measure the tension existing between the soil and the soil water. A porous cup is installed in the soil and connected with the manometer, and the system is then filled with air-free water. Connection between the soil water and water in the instrument is quickly established through the walls of the porous cup and the tension of equilibrium is indicated by the height of the mercury column in the manometer. The tensiometers used in this experiment were constructed at the Citrus Experiment Station. Design and material were similar to those described by Richards (73) with a few minor changes.

1. Filling the tensiometer:——Freshly boiled distilled water is used to fill the tensiometer. Make sure that the outer surface of the porous cup is dry before filling, so that no air will be entrapped in the cup. Allow water to evaporate from the porous cup until the surface of the cup is moist. The remaining air in the system may be pumped out with a rubber bulb atomizer. Close the air trap after all

the air has been expelled.

2. Setting the scale zero:——Filled tensiometer is set in a beaker of water which had been filled to half the height of the porous cup and let stand overnight. Adjust the zero of the scale to the level of the mercury meniscus.

3. Test for air leaks:——Apply suction at the air-trap (use an aspirator pump) until the mercury column is 800 cm or more above the mercury pot and clamp off. If the water in the tensiometer is cool and the excess water on the outside of the porous cup is removed, the mercury column should be stable at 800 cm. It is usually necessary to replace the air which collects in the air trap with boiled water a few times before this tension can be maintained.

Another test method frequently employed is to place the porous cup before a fan to speed the evaporational loss of water from the cup and cause a resultant rise in the mercury column to 800 cm or more. The necessary tension will not develop if there is a leak.

B. Calibration of Tensiometers

The measurement of the tension between the soil and its water yields useful information. But the question immediately arises: What does a given tension mean in terms of quantity of available soil moisture? It should be pointed out here that the tension values are related only to the conditions of available soil moisture. The unavailable soil moisture, whether its quantity large or small, has no effect on tension values. There is an inverse relation between tension values and the

quantities of available soil moisture. In other words, there is no measurable tension existing in a soil that is saturated with water. As the quantity of soil water decreases from the condition of saturation, the tension increases. Thus it is possible to establish the relation between the observed tension and the quantity of soil water.

1. Laboratory calibration.—The open-container method described by Scofield (83) was used for calibrating the tensiometers. Cans 15 cm in diameter and 20 cm in height with a triangular support for the tensiometer were used. The instrument to the right in Figure 14 is a 24-inch tensiometer and the one to the left is a similar one being calibrated in the laboratory. Each can is started out with a high soil moisture content, well above the field capacity. Barley is grown in the can to accelerate the rate of moisture loss from the soil. The whole system is weighed and the mercury reading recorded daily. The percentage of soil moisture is calculated and plotted against the mercury reading each day. At the end of each run the soil moisture is determined by the oven-dry method to check the accuracy of the open-container method.

2. Calibration in the field.—On May 1, 1952 a number of tensiometers were set in Block XIX at different depths, and the tension values were observed and recorded daily. From time to time soil samples were collected in the vicinity of each instrument and the moisture contents determined by oven-drying. In the course of time, it was possible to obtain soil moisture values corresponding to a fairly wide range of

Figure 14.—Right: A 2-foot tensiometer. Left: A 2-foot tensiometer being calibrated in the laboratory.

tension values.

There was no general agreement between laboratory and field calibrations. A comparison of the laboratory and field calibrations for three instruments at different depths is listed in Table 27 and Figures 15,16,17.

Table 27. A Comparison of Laboratory and Field Calibrations of Tensiometers at Different Depths

	Soil Moisture (%)					
Tension (mm Hg)	18" tensiometer		48" tensiometer		72" tensiometer	
	Lab.	Field	Lab.	Field	Lab.	Field
0	29.28	47.12	55.96	97.53	41.88	29.21
25	11.11	11.04	14.30	26.21	9.81	7.30
50	6.89	6.55	7.96	6.05	5.63	4.12
75	5.01	4.79	5.59	3.85	3.98	2.85
100	3.94	3.85	4.35	2.69	3.10	2.16
125	3.26	3.27	3.58	2.16	2.55	1.73
150	2.78	2.88	3.06	1.83	2.17	1.44
175	2.33	2.59	2.69	1.60	1.90	1.22
200	2.16	2.37	2.41	1.44	1.70	1.06
250	1.77	2.06	2.01	1.22	1.40	0.83
300	1.51	1.85	1.74	1.08	1.21	0.67
350	1.32	1.70	1.55	0.99	1.06	0.56
400	1.17	1.59	1.40	0.90	0.96	0.47
450	1.07	1.50	1.29	0.84	0.87	0.41
500	0.96	1.43	1.20	0.80	0.81	0.35
600	0.82	1.32	1.06	0.75	0.70	0.27
700	0.72	1.24	0.96	0.70	0.63	0.22
800	0.65	1.18	0.89	0.65	0.58	0.17

The data in Table 27 have been calculated from the original data with the use of equations described by Scofield (88), so that they can be presented on the same tension basis. Actually field observation showed that soil moisture at 48 and 72 inch depths was never low enough to induce tensions beyond 280 mm and 178 mm. Figures 15,16,17 show

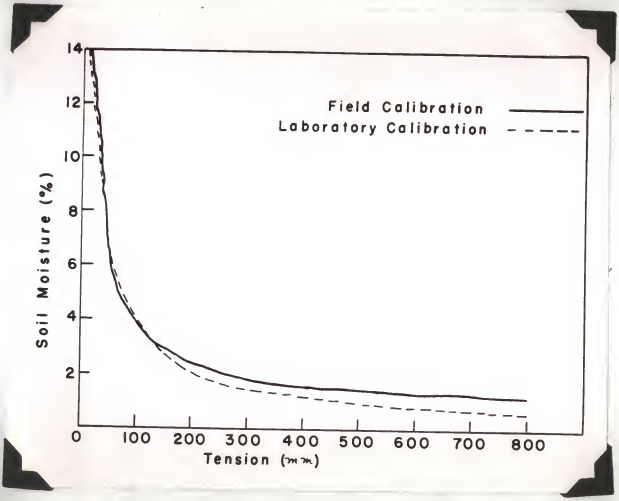


Figure 15.—A comparison of field and laboratory calibrations of a tensiometer at 18-inch depth.

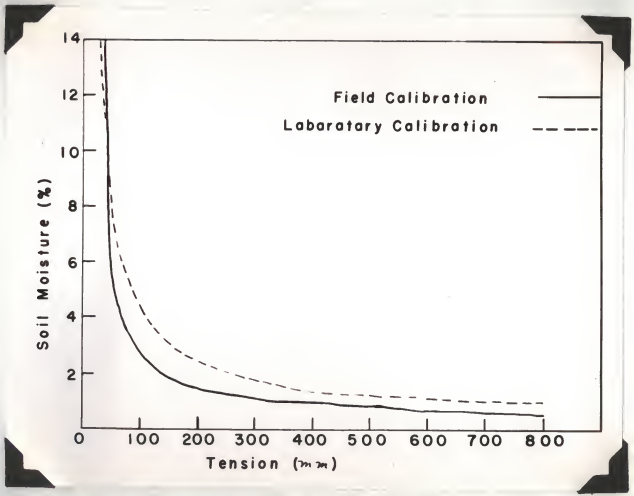


Figure 16.—A comparison of field and laboratory calibrations of a tensiometer at 48-inch depth.

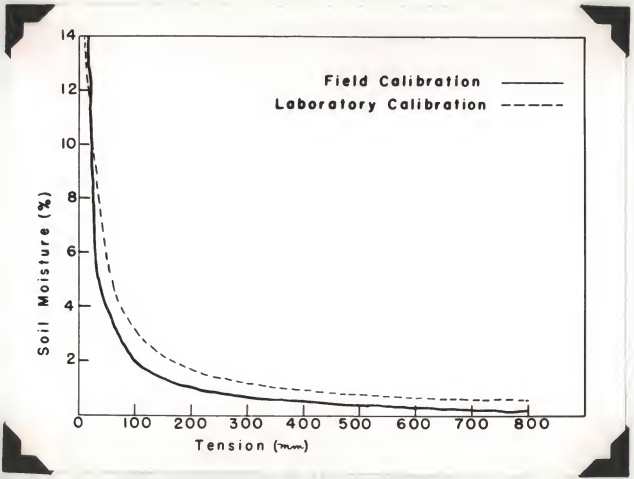


Figure 17.—A comparison of field and laboratory calibrations of a tensiometer at 72-inch depth.

graphic comparisons between the laboratory and field calibrations for the instruments at the 18-inch depth and the ones at the 48-inch and 72-inch depths. The differences can be explained at least in part by the differences in the readily available moisture contents at different depths. All the soil used in the laboratory calibration was collected from the top foot. It had been shown that values of the field capacity and the permanent wilting percentage were not the same at different depths. Hence, the quantity of the readily available moisture at varying depths was also different. Since the tensiometers measure only the available moisture, it is possible to have different moisture contents at different depths even though the tensions are identical.

It is also known that for any given soil, the tension value associated with any given quantity of readily available moisture is influenced by the apparent density of the soil (88). Thus, for any given soil with any given quantity of readily available moisture, the tension values decrease as the apparent density increases or as the soil becomes more compact. Measurement of volume weight for the upper 24 inches of the Lakeland fine sand showed an average increase of 0.07 in the apparent density between the 0-6 inch and 18-24 inch layers (Table 43 appendix). If we assume that the apparent density increases with each increasing depth from the 24-inch to the 72-inch depths in a similar manner, this may partially explain why the tensiometers at 18-inch depth a tension of 100 mm. is equivalent to a soil moisture content of 3.90%, while for the 48-inch instrument the same tension is equivalent to 2.90%, and to 2.17% at the 72-inch depth.

C. Field Observations with Tensiometers

On May 1, 1952 a group of seven tensiometers were installed at depths of 12, 18, 24, 36, 48, 60, and 72 inches in Block XIX (Figure 18). Another group of six instruments was installed at similar block. These instruments were kept in operation until March 15, 1953. The tension was read daily in the morning with the exception of Sundays and holidays. Portions of the data are presented in Table 28 to illustrate the functions of the tensiometers.

The tensiometer is useful in recording the fluctuations of soil moisture through the rise or fall in tension. It has a range of operation from approximately 6.50 to 1.20% of soil moisture, or from above the field capacity to about 15 per cent of the readily available moisture. Aside from recording the soil moisture fluctuations, data in Table 28 demonstrate two other important functions of the tensiometers, namely, that they record the depth of penetration of rain or irrigation water, and that they show the comparative rates of extraction of soil moisture by the roots at different depths.

The depth of penetration by a certain quantity of rainfall or irrigation water is partly dependent on the initial soil moisture content. Data in Table 28 show that it is possible to tell the depth of penetration through the tension fluctuations. For instance on June 4, 1952 0.87 inch of rain penetrated to a depth of approximately 2 feet. The data also illustrate the uneven penetration of the water added, which somewhat curtails the usefulness of the tensiometer as a soil moisture indicator. It is of practical importance from the standpoint of irri-

Figure 18.—Tensiometers installed in the field. From left to right the instruments were installed at depths of 12, 18, 24, 36, 48, 60 and 72 inches.

Table 28. Observed Soil Moisture Tensions at Successive Depth of Lakeland Fine Sand Planted with Marsh Grapefruit Trees. (Expressed as Millimeter of Mercury)

Date	Rainfall Acre-inch	Tensions at indicated depths (inches) 12	18	24	36	48	60	72
June 2, 1952		219mm.	80mm.	105mm.	317mm.	120mm.	100mm.	86mm.
3		277	108	120	399	122	100	85
4	0.87	320	146	144	446	128	101	91
5		56	66	34	515	135	106	98
7		81	86	44	597	143	104	100
9		95	96	86	626	153	104	105
10		103	105	98	641	160	104	110
11		110	118	142	651	170	105	115
12	0.40	120	148	260	659	179	106	122
13	0.20	74	76	290	678	198	110	132
14		62	64	52	676	200	110	130
16	0.07	106	90	62	272	222	112	138
18		142	247	106	102	241	112	158
19	0.07	164	570	106	110	258	114	163
20	1.27	190	714	176	127	287	116	177
21	1.23	50	64	30	72	106	116	185
23		56	64	32	58	59	112	60
24		69	77	40	46	62	114	76
25		79	86	50	50	67	116	82
26	1.47	86	103	56	56	72	114	92
27		35	55	36	36	79	126	54
28		55	64	40	42	62	115	64
Dec. 1, 1952		97	108	156	90	79	100	98
4		104	120	363	96	84	100	96
5	0.07	107	130	484	104	86	101	98
6		107	144	552	107	88	100	96
8		114	160	666	112	90	102	104
9		118	188	700	118	92	102	106
10	0.17	122	219	708	123	94	102	106
11		132	290	739	133	95	102	108
12		118	286	755	84	96	102	111
13	0.47	127	292	764	96	100	104	113
15		59	62	457	100	100	104	112
16		66	70	603	108	102	104	114
17		72	74	660	154	101	106	113
18		77	78	686	156	102	108	114
20	0.13	84	84	712	166	106	111	112
22		92	97	754	196	108	114	116
23		94	96	752	200	108	127	118
26	0.07	102	114	696	224	111	128	118
29		108	146	773	271	113	156	122
30		112	145	764	271	114	156	121

gation to know the depth of penetration of a particular quantity of water applied. The soil tensiometers will furnish this information. In the absence of the tensiometers it is believed that with the aid of the knowledge of the field capacity, it is possible to calculate the depth of penetration of water added with reasonable accuracy, if the soil moisture contents are known. For instance, hypothetically the criterion for irrigation on Lakeland fine sand is whenever the soil moisture content in the upper 6 feet has reached an average of 1.50%. The expected depths of penetration of varying quantity of water applied was calculated in Table 29.

Table 29. Calculations of the Quantity of Water Required at Different Depths to Reach Field Capacity Starting from a Known Soil Moisture Content, and the Probable Depths of Penetration of Water Applied on Lakeland Fine Sand

Soil Depth (inches)	Gallons of Water per Tree Present in Soil when Soil Moisture Content is 1.50%	Field Capacity	Needed to reach Field Capacity from 1.50% in Each Layer	Total Depth	Rainfall Needed to reach Field Capacity at Given Depth
0- 6	52	167	115	115	
6-12	52	163	111	226	
12-18	52	149	97	323	
18-24	52	148	96	419	1 inch or 387
24-36	104	281	177	596	
36-48	104	270	166	763	
48-60	104	246	142	905	2 inches or 774
60-72	104	240	136	1041	3 inches or 1161

This is a hypothetical case. Under field conditions the soil moisture contents will seldom be uniform at different depths. Nevertheless, if the soil moisture contents at different depths are known prior

to irrigation the depth of penetration of water can easily be calculated.

Another function of the tensiometers is to show the comparative rates of extraction of moisture by the roots at different depths. When reading the data in Table 28 it should be borne in mind that soil moisture and tension do not assume a linear relationship. As shown in Table 27 and Figures 15,16,17 at higher tension ranges, the tension may rise considerably while there is little change in the soil moisture contents. To a lesser degree there are also variations among instruments at different depths because of the different apparent soil densities as well as variations among individual instruments. In other words, a given tension on different instruments does not necessarily represent the same moisture content. The data show that there were higher rates of moisture extraction at depths closer to the surface than at the lower depths and higher rates of moisture extraction in summer months when the rates of transpiration were higher than in winter months. From June 5 to June 12, 1952 there was a rise in the tension on the 12-inch instrument from 56 mm. to 120 mm. in eight days while the rise on the 72-inch instrument was from 98 mm. to 122 mm.. When stated in terms of soil moisture content, there was a drop from 6.00 to 2.70% at the 12-inch depth and from 2.20 to 1.80% at the 72-inch depth. Compare the same period with that from December 15 to December 22, 1952, when the 12-inch tensiometer showed a rise from 59 mm. to 92 mm., a rise of 33 mm. as compared with a rise of 64 mm. on the same instrument in the same number of days in June.

D. Discussion

The advantages and disadvantages of the soil tensiometers may be summarized as follow:

Advantages:

1. The soil moisture tensiometer is useful as a soil moisture indicator. It will cover a range from above the field capacity to about 15 per cent of the readily available moisture.

2. It is useful in indicating the depth of penetration of rain and irrigation water.

3. It is useful in studying the comparative rates of moisture extraction by the roots at different depths and at different seasons.

Disadvantages:

1. It will only indicate the soil moisture content immediately around the porous cup. With as much variation as there is in the moisture content from one location to another on Lakeland fine sand, the usefulness of the tensiometers as well as any other types of moisture indicator is greatly limited unless many instruments are available. In order to obtain reading representative of the soil moisture within a 10 per cent error, it is necessary to have at least 3 instruments to an acre at the desired depths (Table 2).

2. Because of variations among the instruments, each instrument must be calibrated individually. The lack of a satisfactory laboratory method for calibration makes it necessary to calibrate the instruments in the field.

Once the tensiometers are installed, there is little to be done

other than to take the readings. Diurnal fluctuation is not a factor as long as the readings are taken at about the same time each day. Any abrupt change in temperature will cause fluctuations in the mercury manometer, but it will return to normal as soon as an equilibrium is established between the temperature in the porous cup and the soil temperature. Occasionally an air bubble may appear in the mercury manometer. This can easily be pumped out with the use of a rubber bulb atomizer at the air trap, which must then be refilled with freshly boiled, distilled water.

Based on the distributions of feeder root and the pattern of rainfall, it is recommended that the tensiometers be installed at depths of 18-24 inches and 48 inches. Distribution of feeder roots showed a sharp reduction below the 48-inch depth. As a result there is comparatively little moisture fluctuation in zones below the 48-inch depth. The precipitation records for 1952 showed that the majority of the rainfall is one acre-inch or less. It is not often that rains would penetrate more than 24 inches. On numerous occasions there was a relatively moist zone from 6 to 24 inches, and a dry zone from 24 to 42 inches. By installing tensiometers at depths of 18-24 inches and 48 inches, it is possible to account for most moisture fluctuations in the critical zones.

VI. DISCUSSION

One of the major problems associated with irrigation of citrus in Florida is to determine when to irrigate. Various methods have been used but none has emerged as satisfactory, practical and economical. The object of irrigation is to prevent the tension of the soil moisture from reaching such a high value that plant growth, development and yield are appreciably depressed. It is not understood exactly what effects different soil moisture tensions have on different plant functions. Apparently various plant functions do not take place independently of the soil moisture tension. The rate of transpiration has been shown to be at a maximum somewhere in the low tension range. When more than two-thirds of the readily available moisture has been removed there is a decline in the rate of transpiration until near the permanent wilting percentage when transpiration is at a minimum.

In order to determine in the field the time at which the moisture supply of the soil has been depleted by the plants to a critical point, it is necessary to measure either the soil moisture tension or the soil moisture percentage. For this purpose there are the soil moisture tensiometers which measure the soil moisture tension directly and many other types of instruments which measure indirectly the soil moisture percentage. However, even in research work these instruments have proven to be expensive, both as to actual cost and in time required for operation and interpretation. For practical use by growers, they are generally unsatisfactory. Moreover, there has been no single

method developed in the laboratory suitable for field use. This is mainly due to the small volume of soil measured and the resultant variations between replicate installations.

Determination of moisture through soil sampling is probably more accurate, but is laborious and time consuming. Because of the wide variations in the soil moisture contents from one location to another, it is necessary to collect large numbers of samples to obtain representative results.

A. The Use of Climatological Data in Determining the Time of Irrigation

A somewhat different approach to the problem of determining the status of soil moisture at any given time is the indirect means of accounting for differences between additions and losses of water to and from the soil. This is the approach used in the present experiment. By breaking down quantitatively the sources from which moisture is lost from the soil, it is possible to calculate the quantity of water removed by the trees and other sources if the amount of water added to the soil is known. Once the quantitative losses of different sources are known, it is possible to establish the relationship with climatological factors such as temperature and relative humidity.

A number of formulas based on climatological data have been advanced by different workers to estimate the evaporation and transpiration (evapo-transpiration). However, because of the limited data at hand the accuracy of these formulas are doubtful and at best they are only empirical. Nevertheless such an approach is certainly an advance

in the right direction. Thornthwaite (95) has proposed an empirical formula based on latitude and average temperature of the air as the only variables. Another formula proposed by Blaney and Criddle (6) is based on the average monthly daytime hours between sunrise and sunset and the average monthly temperature. In addition to those variables their formula also makes use of a consumptive-use coefficient, which can be used to account for variations due to thickness of vegetation, stage of crop and other variables. In Table 30 and Figure 19 are shown the monthly average evapo-transpiration for Block XIX calculated according to Thornthwaite and to Blaney and Criddle, together with actual measurements made in the field for 1952.

Table 30. A Comparison of the Calculations by Different Formulas Using Climatological Data to Estimate Evapo-transpiration Against Actual Measurement in the Field

Month	Thornthwaite	Blaney-Criddle	Block XIX
	gal./tree	gal./tree	gal./tree
Jan.	686	1015	769
Feb.	483	914	565
March	1005	1214	1043
April	1118	1270	1244
May	2123	1565	1399
June	2919	1669	1902
July	2873	1683	1858
Aug.	2455	2576	1736
Sept.	2325	1441	1550
Oct.	1375	1247	1534
Nov.	741	1015	706
Dec.	371	899	619

Blaney and Criddle's formula gave results in agreement with field measurement of evapo-transpiration only in April, May and September. In general, the calculated results were higher in the winter

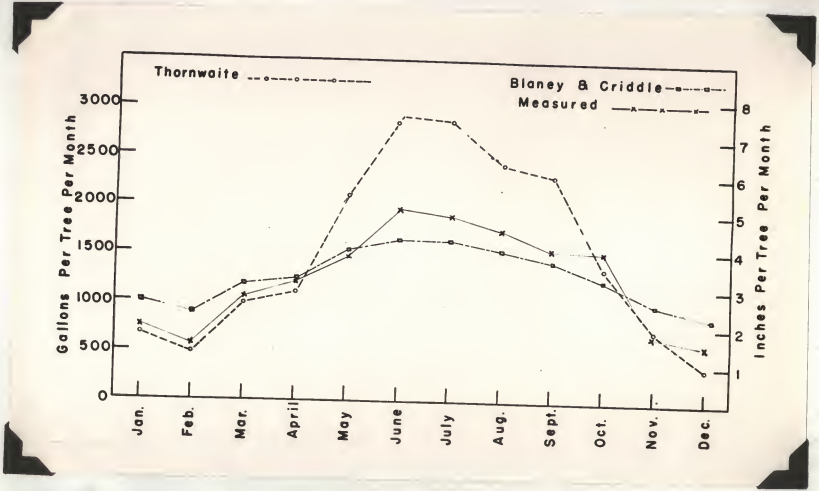


Figure 19.—Estimated evapo-transpiration calculated from Thornthwaite's and from Blaney and Criddle's formulas as compared with the actual measurement made in the field.

and lower in the summer. This is because Blaney and Criddle assume a linear relationship between temperature and the rate of transpiration in establishing the formula. It has been shown in the present investigation that this relationship is not linear but curvilinear. Also the deviations of some of the consumptive-use coefficients are open to question.

When compared with actual measurement in the field, calculations from Thorntwaite's formula are satisfactory for the months from October through April, but are too high during the summer months. From the standpoint of irrigation the more critical months are those of good agreement.

The chief disadvantage of the formulas based on climatological data is that they assume that there is an ample supply of soil moisture, i.e. the availability of the soil moisture is not taken into consideration. When the soil moisture contents are low, the calculations are somewhat off, as shown in May and September, 1952. It was found necessary to irrigate in May, 1952. Although the soil moisture contents in September was not as low as in May, there were periods of no rain from August 28 to September 8 and again from September 10 to 20. Calculations based on climatological data for these two months showed considerably more moisture was lost for those two months than field measurement would indicate. It has not yet been established definitely at what moisture level the critical point is when irrigation should be applied. Even if the critical point is considered as the point when more than two-thirds of the readily available moisture has been removed,

under field conditions this point will not be reached simultaneously at different depths. As a result, the rate of moisture extraction by the roots at different depths will be affected by the uneven soil moisture contents at different depths. Climatological data alone cannot account for these differences.

The use of climatological data in forecasting the time of irrigation is a different but hopeful approach to the problem. However, due to the limited information available at present, the accuracy of such an approach is open to question. Although Thornthwaite's method of calculation is reasonably accurate from October through April when compared with actual field measurement, improvements could be made. If the effects of the availability of soil moisture can be taken into consideration, it is believed that further accuracy can be gained. It should also be pointed out that while actual field measurement is used as a basis for comparison, it also certainly is subject to certain errors.

B. Some Practical Considerations in Determining Time of Irrigation

Based on results of this investigation certain information may be useful in considering the time of irrigation. For any given grove it is of practical value to know the depth to the clay layer (hardpan) or the water table if the latter should remain above the former. It is of particular importance to know the field capacity of the soil in question, so that one can calculate the maximum amount of water a given soil is able to hold. A deep soil will hold more water than a shallow soil. Although when individual layers are considered, the shallow soil

may have a higher field capacity at any particular unit depth than the deep soil because of the differences in drainage tension, yet the extra space and moisture available to the roots will more than compensate for the difference in field capacities. Knowledge of the permanent wilting percentage is useful in determining the unavailable moisture and together with field capacity enables the readily available moisture to be determined. With this knowledge in mind and if the quantity of water added to the soil is known, it is possible to calculate with reasonable accuracy the soil moisture contents at any given time over a given temperature range. For instance, the present investigation was terminated on February 27, 1953 in Block XIX. No soil moisture measurements were made during the month except on March 31 to serve as a check. The average temperature for the month of March was 70° F. Figure 6 showed that at 70° F the moisture loss from transpiration and evaporation was 35.5 gallons per tree per day, or 1,136 gallons per tree for the whole month. Soil moisture contents determined on March 31 indicated that there were 910 gallons per tree to a depth of 6 feet as compared with a soil moisture content of 1,478 gallons on February 27. There was a loss of 568 gallons per tree for the month of March. The precipitation record for the month showed a rainfall of 1.67 acre-inch which was equivalent to 647 gallons per tree. The total moisture removed from the soil for March was 1,215 gallons per tree (647 + 568). When it is compared with the calculated sum of 1,136 gallons per tree, there was a discrepency of 79 gallons per tree or an error of 6.5% which could have easily occurred in the soil sampling. If the critical point for irrigation is

when more than two-thirds of the readily available moisture has been removed from the soil, it will leave a margin of approximately 290* gallons per tree or 8 more days at the prevailing temperature in March.

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* 910 - 620 = 290 gallons per tree. 620 gallons per tree represents the sum of the permanent wilting percentage and one-third of the readily available moisture.

VII. SUMMARY

1. Soil moisture fluctuations on Lakeland fine sand planted with Marsh grapefruit trees were studied from October 1, 1951 to March 1, 1953.

2. The number of samples required for different fiducial limits for different depths were calculated.

3. There was a close correlation between the distribution of feeder roots and moisture loss at different depths.

4. The field capacity was measured in the field at 6-inch intervals to 24 inches and at 12-inch intervals from 24 to 72 inches. The results varied from 4.85% in 0-6 inch zone to 3.38% in the 66-72 inch depth. Results of laboratory measurements were in agreement with field study.

5. Estimations of water loss showed percolation will usually take place when the rainfall exceeds 3 acre-inches. Leaching accounted for approximately 30 per cent of total moisture loss over the period studied.

6. The permanent wilting percentage varied from 0.80% in the surface 12 inches to 0.60% between 48 and 72 inches.

7. Evaporational loss from soil accounted for approximately 9 per cent of the total moisture loss. About three-fourths of the evaporation takes place in the 0-6 inch depth. Statistical analysis showed a highly significant multiple correlation to air temperature and percentage soil moisture in the upper 24 inches.

8. Moisture removed from the soil by the trees accounted for

60 per cent of the total moisture loss. The quantity of water removed by the tree is closely correlated with the air temperature. The relation between air temperature and the rate of water loss by transpiration and evaporation is presented.

9. The results of pot experiments and field observations indicated that the readily available moisture was not equally available over the entire range from the field capacity to the permanent wilting percentage. There was a decline in the rate of transpiration when more than two-thirds of the readily available moisture was removed from the soil.

10. The practical application of the soil moisture tensiometer as a moisture indicator was studied. While the performance of the tensiometer is satisfactory, its usefulness is greatly limited by variations in the soil moisture contents on sandy soils. The advantages and disadvantages of the tensiometer are discussed.

11. The possibility of applying climatological data in estimating the time of irrigation is considered. Thornthwaite's formula gave reasonably accurate predictions from October through April when compared with actual measurements made in the field.

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IX. APPENDIX

Table 31. Average Soil Moisture Content at Different Depths from October, 1951 through February, 1953, on Lakeland Fine Sand Expressed in Percentage of Oven-dry Weight (Block XIX)

Date	Depth(inches) 0-6	6-12	12-18	18-24	30-36	42-48	54-60	66-72
Oct. 1, 1951	7.49	6.33	5.89	5.70	5.55	6.04	5.52	5.42
8	2.64	3.15	3.27	3.30	3.37	3.63	4.22	4.38
15	2.29	2.41	2.52	2.31	2.46	2.67	3.04	3.04
22	2.48	2.52	2.19	1.77	2.06	2.30	2.62	3.05
29	4.46	3.67	3.59	3.41	1.99	2.02	2.16	2.57
Nov. 5, 1951	2.41	2.21	1.96	1.40	1.11	1.43	1.70	1.89
13	1.62	1.78	1.57	1.19	1.04	1.15	1.42	1.42
19	4.71	4.42	4.13	4.41	4.44	4.60	4.85	5.71
26	2.84	3.56	3.24	3.34	3.42	3.43	4.06	4.01
Dec. 3, 1951	2.43	3.04	2.95	3.00	2.94	3.08	3.08	3.23
10	3.60	3.46	3.43	3.46	3.43	3.54	3.50	3.82
17	4.61	4.29	3.71	3.23	2.91	2.94	2.94	3.11
27	4.26	4.48	4.29	4.14	3.40	3.47	3.38	3.37
Jan. 2, 1952	3.72	4.16	4.16	3.79	3.78	3.41	3.11	3.30
7	3.75	3.67	3.37	3.38	3.52	3.35	2.99	3.15
14	2.85	2.85	3.31	3.02	2.97	3.01	3.11	3.09
21	2.74	3.17	3.10	3.15	2.84	2.91	2.99	3.04
28	2.24	2.64	2.61	2.22	2.21	2.46	2.63	2.78
29	4.27	2.94	2.45	2.04	1.94	2.15	2.39	2.47
Feb. 4, 1952	4.87	4.50	4.08	3.52	2.29	2.36	2.61	2.80
5	6.92	4.85	4.18	3.42	3.04	2.73	2.43	2.63
11	3.77	4.10	3.84	3.94	2.93	2.76	2.56	2.34
17	5.54	5.15	5.24	4.72	3.48	3.03	2.94	2.90
25	6.81	6.01	5.55	5.58	5.48	4.59	3.67	3.35
27	6.03	5.35	5.15	5.21	5.34	5.45	5.07	5.42
Mar. 3, 1952	3.59	4.37	4.34	3.90	4.13	4.15	4.14	5.15
6	3.10	3.76	3.64	4.20	3.99	3.84	4.43	3.75
10	2.54	3.08	3.08	3.18	3.27	3.45	3.51	3.59
13	3.12	3.14	3.21	3.20	3.36	3.48	3.55	3.55
15	5.84	5.78	5.53	5.49	6.11	6.13	5.72	5.32
20	3.82	4.03	4.12	4.11	4.14	4.14	4.00	4.81
24	2.71	3.29	3.64	3.58	3.61	3.70	4.25	4.02
28	6.23	5.77	5.49	5.35	5.26	5.79	5.95	6.37
31	4.09	4.41	4.16	4.24	4.63	4.63	4.51	5.35

Table 31.—Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24	30-36	42-48	54-60	66-72
Apr. 3, 1952	3.44	4.25	4.22	4.19	4.50	4.24	4.26	4.55
7	2.22	3.14	3.38	3.33	3.50	3.63	3.67	3.76
10	2.52	3.52	3.26	3.51	3.58	3.51	3.53	3.49
14	2.12	2.64	2.86	2.83	2.94	3.24	3.13	3.47
21	1.73	2.47	2.38	2.10	2.12	2.52	2.93	2.93
24	1.36	1.99	2.05	1.87	1.71	2.02	2.28	2.54
28	4.26	4.17	3.97	3.13	2.77	2.50	2.82	2.73
May 2, 1952	2.61	2.53	2.96	2.51	2.34	2.62	2.93	3.10
5	2.28	2.75	2.70	2.29	1.96	2.12	2.46	2.55
9	1.55	2.21	2.02	1.63	1.30	1.66	2.03	2.23
12	1.29	1.75	1.74	1.44	1.35	1.77	2.17	2.28
19	3.91	3.74	3.06	2.83	2.88	2.91	2.65	2.63
23	3.84	3.52	3.48	3.33	3.17	2.90	3.09	3.51
27	1.84	2.15	1.94	1.76	1.80	2.10	2.30	2.50
31	4.39	3.03	2.24	1.80	1.61	2.00	2.37	2.59
June 5, 1952	5.67	4.52	4.19	3.75	2.71	2.20	2.15	2.34
11	2.16	2.79	2.77	2.48	1.59	1.49	1.67	1.97
14	4.86	3.26	2.81	2.24	1.59	1.73	1.85	2.04
20	1.87	2.11	1.93	1.65	1.29	0.97	1.06	1.22
23	5.04	5.12	5.16	4.68	3.74	2.63	1.94	1.77
27	7.32	5.85	5.16	5.22	4.65	2.99	2.01	1.93
30	2.31	3.68	3.58	3.70	3.60	3.09	2.43	2.24
July 2, 1952	5.09	4.86	3.89	3.71	3.47	2.85	2.61	2.73
7	4.79	4.15	3.71	3.71	3.64	3.43	3.03	3.11
11	5.94	5.89	5.05	4.90	4.51	4.08	3.52	3.52
15	4.99	4.55	4.01	4.24	4.03	3.87	3.45	3.24
19	2.23	2.63	2.97	3.13	2.56	2.50	2.86	2.90
25	1.56	1.64	1.85	1.73	1.78	2.02	2.32	2.36
30	4.96	4.27	3.31	2.36	2.16	1.60	2.04	2.35
Aug. 2, 1952	6.03	5.01	4.22	4.19	3.06	2.70	2.78	2.52
6	6.43	5.99	5.32	5.11	4.57	3.98	4.10	4.81
9	5.01	4.60	4.26	4.32	4.15	3.75	3.98	3.94
13	6.94	6.47	5.99	6.19	4.71	3.86	4.16	4.45
16	4.01	4.59	4.11	4.46	3.84	3.90	4.06	3.91
20	5.63	5.42	5.24	5.62	5.95	5.00	3.95	4.34
23	3.77	4.04	4.02	4.39	4.37	4.06	4.23	3.98
26	6.09	5.90	5.43	6.01	5.92	5.13	4.41	4.59
30	4.55	3.88	3.88	3.99	4.29	4.69	4.66	4.66

Table 31.—Continued

Date	Depth (inches) 0-6	6-12	12-18	18-24	30-36	42-48	54-60	66-72
Sept. 3, 1952	2.66	3.13	3.09	3.14	3.39	3.56	3.84	4.11
5	2.97	2.90	2.82	2.82	2.99	3.25	3.51	3.62
9	5.30	4.42	3.73	2.92	2.66	3.23	3.27	3.31
12	4.67	4.33	3.81	2.99	3.00	2.95	3.21	3.44
17	2.23	2.39	2.38	1.81	1.68	2.14	2.63	2.68
20	3.62	2.53	2.28	1.87	1.77	1.95	2.27	2.46
24	5.19	5.06	4.86	4.04	2.71	1.99	2.45	2.58
27	4.60	4.83	4.47	4.65	5.33	5.33	5.34	5.23
Oct. 1, 1952	5.40	5.18	4.87	5.06	5.45	5.11	5.30	5.19
4	3.65	4.17	3.97	4.10	4.32	4.28	4.65	4.61
7	7.03	6.68	6.04	5.81	5.78	5.55	5.32	4.86
10	5.01	4.63	4.46	4.64	4.86	4.91	5.03	4.82
15	3.48	3.85	3.75	3.95	4.04	4.21	4.39	4.54
18	6.81	5.99	5.55	5.61	6.10	6.23	6.42	6.20
21	6.58	5.56	5.25	5.37	5.85	5.92	6.43	6.55
25	4.95	4.60	4.57	4.51	4.57	4.44	4.48	4.57
29	3.98	3.79	3.76	3.67	3.69	3.61	3.74	3.87
Nov. 3, 1952	2.89	3.16	3.19	3.13	3.06	3.13	3.25	3.32
7	2.74	3.10	2.90	2.80	2.72	2.98	3.10	3.23
12	2.24	2.55	2.56	2.37	2.34	2.65	2.73	2.93
17	1.61	2.25	2.21	1.89	1.73	2.24	2.43	2.56
21	5.69	5.51	4.41	3.43	2.77	2.94	2.64	2.64
26	2.92	3.92	3.62	3.85	3.81	3.63	3.17	3.17
Dec. 1, 1952	2.61	3.80	3.37	3.14	2.55	2.42	2.71	2.71
6	2.27	2.99	3.06	2.72	2.13	2.14	2.42	2.48
10	2.23	2.96	2.79	2.29	1.75	1.80	2.19	2.62
15	4.21	3.79	3.29	2.83	2.49	2.35	2.21	2.43
22	3.39	4.14	3.72	3.38	2.64	2.03	2.14	2.31
29	3.35	3.61	3.12	2.17	1.57	1.57	2.05	2.20
Jan. 3, 1953	3.88	4.44	3.84	3.11	2.14	2.04	2.18	2.24
10	5.53	6.07	4.93	4.76	3.63	3.12	2.38	2.36
14	3.79	4.77	4.68	4.07	3.87	3.15	2.36	2.16
20	2.81	3.64	3.70	3.59	2.81	2.09	2.22	2.28
24	7.07	5.62	4.61	4.29	3.09	2.83	2.49	2.36
29	3.50	4.16	3.71	3.36	2.65	2.28	2.25	2.35

Table 31.—Continued

Date	Depth (inches) 0-6	6-12	12-18	18-24	30-36	42-48	54-60	66-72
Feb. 4, 1953	5.03	4.84	4.03	3.56	2.71	2.34	2.34	2.42
8	5.89	6.24	5.48	5.52	5.03	3.86	3.37	3.34
12	4.24	4.44	4.07	3.95	3.46	3.50	3.15	3.59
17	4.89	5.32	4.94	4.75	4.16	4.03	3.80	3.75
21	3.47	3.99	3.84	3.77	3.79	3.63	3.10	2.78
27	3.44	3.80	3.72	3.62	3.58	3.60	3.46	3.50

Table 32. Precipitation Record from October, 1951 to March, 1953 at Block XIX

Date	Acre-inch	Month Total (acre-inch)	Date	Acre-inch	Month Total (acre-inch)
10-15-51	0.07		6- 4-52	0.87	
22	0.13		13	0.60	
26	0.33		16	0.07	
28	0.07		19	0.07	
		0.60	20	1.27	
11- 2-51	0.13		22	1.23	
17	4.30		26	0.54	
		4.43	27	0.93	
12- 4-51	1.33				5.58
15	0.27		7- 1-52	0.87	
18	0.90		2	0.33	
22	0.27		4	0.07	
		2.77	6	0.20	
1- 6-52	0.13		10	2.07	
28	0.47		13	0.30	
		0.60	21	0.17	
2- 5-52	1.23		27	0.17	
17	1.03		29	0.87	
21	0.07		31	0.77	
24	1.20				5.82
27	2.33		8- 1-52	0.40	
		5.86	2	2.73	
3- 6-52	0.07		5	0.80	
11	0.10		7	0.07	
15	3.17		8	0.07	
28	3.10		9	0.10	
		6.44	10	0.93	
4- 8-52	0.30		12	1.07	
27	1.80		18	1.30	
		2.10	20	0.20	
5-14-52*	2.25		24	0.57	
17	0.17		25	0.93	
22	0.13		28	0.13	
23	0.07				9.30
27	0.07		9- 8-52	0.67	
30	0.27		10	0.20	
31	0.13		19	0.10	
		3.09	20	0.10	

*Irrigated 2.25 acre-inch on this day.

Table 32.—Continued

Date	Acre-inch	Month Total (acre-inch)	Date	Acre-inch	Month Total (acre-inch)
9-21-52	0.07		11-21-52	1.33	
22	0.07				1.33
23	1.07		12- 5-52	0.07	
24	1.90		10	0.17	
25	0.07		14	0.47	
27	0.33		21	0.13	
29	1.00		28	0.07	
30	0.03		31	0.47	
		5.95			1.38
10- 7-52	2.00		1- 8-53	0.13	
8	0.40		9	1.33	
15	0.07		10	0.07	
18	2.93		24	0.80	
20	1.73				2.33
21	0.27		2- 2-53	0.27	
22	0.30		8	1.80	
27	0.07		15	0.54	
		7.77	22	0.23	
					2.84

Table 33. Soil Moisture Variations Found at 6 Inch Intervals in 0-24 Inch Depth in four and one-half Acre Marsh Grapefruit (Block XIX), February 12, 1953

Depth(inches)			
0-6	6-12	12-18	18-24
4.69%	3.74%	3.40%	3.38%
5.51	4.78	4.89	4.76
2.89	4.05	4.02	3.92
5.97	5.34	4.23	4.47
2.39	3.84	3.40	4.02
4.16	4.22	4.35	4.60
3.69	3.80	3.61	4.11
2.82	4.89	3.44	3.80
4.25	5.15	4.52	4.18
3.03	3.56	3.02	3.17
4.92	5.56	4.45	4.11
4.49	4.73	4.23	4.86
2.91	3.81	4.26	4.05
3.02	5.43	4.49	4.48
4.14	4.30	4.52	4.60
3.69	3.88	4.02	3.92
4.62	5.23	4.36	4.75
5.86	4.51	4.64	4.88
4.62	4.55	4.41	4.66
4.09	4.91	4.45	4.28
4.29	4.23	4.64	4.70
4.27	3.88	4.65	3.60
5.28	5.40	3.88	0.95
3.57	4.36	4.25	4.43
1.43	4.23	3.76	2.04
0.60	5.57	3.54	2.89
2.25	4.15	2.97	3.09
3.74	4.74	3.96	3.79
4.05	4.65	3.70	4.01
5.22	5.04	3.42	3.83
6.05	4.13	4.36	4.52
4.91	4.26	4.09	4.55
4.40	3.98	4.14	4.50
6.11	1.86	4.09	4.03
4.73	3.42	4.74	4.66
4.12	4.84	4.10	4.13
$\bar{x}$ = 4.08%	$\bar{x}$ = 4.42%	$\bar{x}$ = 4.07%	$\bar{x}$ = 4.02%
s^2 = 1.580	s^2 = 0.547	s^2 = 0.228	s^2 = 0.651
$t_{95\%}$ = 2.03	$t_{95\%}$ = 2.03	$t_{95\%}$ = 2.03	$t_{95\%}$ = 2.03

Table 34. Soil Moisture Variations Found at 6 Inch Intervals in 30-72 Inch Depth in four and one-half Acre Marsh Grapefruit (Block XIX), February 12, 1953

Depth(inches)			
30-36	42-48	54-60	66-72
3.38%	3.34%	4.12%	4.25%
4.13	4.14	4.17	4.02
4.77	4.39	3.85	4.14
1.36	1.07	1.11	1.21
4.14	4.29	3.19	3.14
4.27	4.14	4.29	4.24
4.04	3.50	3.72	3.78
3.07	3.63	3.74	3.34
3.51	3.21	3.68	3.81
3.60	4.06	3.43	3.60
3.20	3.64	4.50	2.85
3.60	3.33	3.22	3.53
4.03	3.73	2.56	4.12
3.53	3.57	3.63	3.74
4.12	4.14	4.29	2.32
3.03	3.42	3.08	3.16
2.98	3.30	2.12	4.49
3.76	3.98	3.60	3.34
$\bar{x}$ = 3.58%	$\bar{x}$ = 3.60%	$\bar{x}$ = 3.46%	$\bar{x}$ = 3.50%
s^2 = 0.546	s^2 = 0.540	s^2 = 0.709	s^2 = 0.632
$t_{95\%}$ = 2.110	$t_{95\%}$ = 2.110	$t_{95\%}$ = 2.110	$t_{95\%}$ = 2.110

Table 35. Field Capacity Measurement at Different Depths Expressed as Percentage Moisture (Samples taken from buried oil drums used for studying evaporation losses)

	Days after wetting	Depth (inches) 0-6	6-12	12-18	18-24
Replication I (west)	1	5.57%	5.55%	4.98%	5.26%
	2	5.21	5.37	4.41	4.58
	3	5.83	4.46	4.15	4.13
	4	5.89	5.13	4.58	4.59
	5	5.42	4.83	4.57	4.64
	6	5.95	4.73	4.17	3.80
	7	5.45	5.08	4.30	4.50
	9	4.84	4.06	4.04	4.07
	11	5.12	4.59	4.53	4.61
	14	4.23	4.31	3.66	3.79
	17	4.32	4.13	4.06	4.17
	24	3.93	4.29	3.72	3.74
	Field Capacity*	4.40%	4.32%	3.99%	3.74%
Replication II (inside canopy)	1	7.06%	6.59%	4.92%	5.66%
	2	6.76	6.17	6.47	4.64
	3	5.83	7.06	5.35	5.28
	4	6.65	6.06	5.11	3.63
	5	6.49	5.71	4.46	4.61
	6	6.39	5.63	5.48	6.33
	7	6.28	5.14	4.51	4.50
	8	6.34	5.88	5.35	4.84
	10	5.68	5.80	5.89	5.11
	13	4.90	5.21	4.28	4.03
	16	5.25	5.05	4.51	4.28
	23	5.25	4.88	4.41	4.11
	Field Capacity**	5.31%	5.23%	4.52%	4.38%

Table 35.—Continued

	Days after wetting	Depth (inches) 0-6	6-12	12-18	18-24
Replication III (north)	1	7.13%	6.16%	5.96%	5.84%
	2	5.99	5.63	5.29	5.65
	3	5.58	5.60	5.39	5.61
	4	5.50	5.46	5.18	5.54
	5	5.77	5.40	4.99	4.99
	6	5.73	5.59	5.78	5.12
	7	5.68	6.28	4.98	4.99
	8	5.55	5.20	5.21	4.90
	10	5.28	5.24	4.99	4.91
	13	4.88	5.14	4.54	4.82
	16	5.27	4.67	4.89	4.58
	23	4.83	4.20	3.91	4.25
	Field Capacity**	5.07%	4.81%	4.58%	4.63%
Replication IV (east)	1	6.25%	6.36%	5.36%	5.21%
	2	5.45	5.45	4.68	4.57
	3	4.98	5.35	4.45	4.40
	4	5.43	5.58	4.81	4.69
	5	4.93	5.15	4.47	4.39
	6	5.73	5.00	4.29	4.20
	7	5.18	5.08	4.75	4.18
	9	5.17	5.68	4.84	4.37
	11	5.07	5.39	4.51	4.46
	14	4.48	5.02	4.42	3.89
	17	4.39	4.75	4.43	4.48
	24	4.52	4.56	4.20	4.06
	Field Capacity*	4.61%	4.93%	4.39%	4.22%

* Obtained from the average of 11-24th day.
** Obtained from the average of 10-23rd day.

Table 36. Soil Moisture Changes in Lakeland Fine Sand Resulting from Evaporation at Varying Depths, from November 19, 1951 to July 10, 1952, Expressed as Percentage Soil Moisture

Date	Depth(inches) 0-6	6-12	12-18	18-24
Nov. 19, 1951	4.79%	5.23%	5.32%	5.72%
21	3.64	4.63	4.41	4.60
23	3.44	5.02	4.61	4.99
26	3.66	4.44	4.41	4.29
28	4.21	4.87	4.39	4.44
Dec. 3, 1951	4.09	4.33	4.11	4.12
5	5.90	6.10	5.82	6.28
7	6.13	6.33	5.78	5.95
10	5.02	5.02	4.95	4.98
12	4.44	4.51	4.53	4.49
14	4.45	4.36	4.65	4.44
17	4.83	5.38	5.44	5.00
19	7.62	7.45	7.63	6.97
21	5.34	6.07	6.09	6.22
27	4.87	5.23	5.07	5.50
Jan. 2, 1952	3.85	4.55	4.96	5.18
4	3.85	5.07	5.59	5.20
7	4.40	4.50	4.52	4.68
9	3.99	4.77	4.66	4.72
11	3.36	4.39	4.23	4.49
14	3.63	4.40	4.30	4.54
16	3.97	4.43	4.40	4.75
19	3.67	3.93	3.72	3.76
21	4.36	4.74	4.48	4.77
24	2.96	4.40	4.01	3.97
28	3.71	4.26	4.19	4.15
29	5.81	4.61	4.68	4.81
Feb. 1, 1952	3.05	4.46	3.85	4.17
4	5.81	5.90	6.65	6.77
5	7.40	6.54	6.50	6.57
7	6.55	6.25	6.91	6.86
11	3.70	5.12	5.19	5.56
17*	6.39	6.45		
21	5.05	5.06		

*Beginning this day samples were collected at 0-6 and 6-12 inch depths.

Table 36.--Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Feb. 25, 1952	8.36%	7.27%		
27	7.24	6.46		
Mar. 3, 1952	4.34	5.19		
6	4.38	4.83		
10	3.68	4.24		
13	4.04	3.65		
15	5.99	7.42		
20	4.52	4.65		
24	2.99	3.21		
28	5.61	5.58		
31	3.85	4.74		
Apr. 3, 1952	3.67	4.79		
7	2.51	3.97		
10	3.16	4.57		
14	2.18	4.83		
21	1.57	3.04		
24	1.67	3.95		
28	3.82	5.30		
May 2, 1952	2.88	5.32		
5	2.74	4.74		
9	0.92	3.77		
12	1.70	3.61		
19	3.59	3.26		
23	2.37	4.79		
27	1.06	3.42		
31	4.20	5.50		
June 5, 1952	5.24	6.44		
11	3.05	4.13		
14	5.10	5.95		
20	4.09	5.30		
23	4.13	5.66		
27	7.13	6.98		
30	4.14	4.35		
July 2, 1952	5.41	6.48		
7	5.44	5.34		
10	4.01	4.48		

Table 37. Soil Moisture Changes in Lakeland Fine Sand Resulting from Evaporation at Varying Depths, from July 10, 1952 to February 28, 1953, Expressed as Percentage Soil Moisture (North)

Date	Depth(inches) 0-6	6-12	12-18	18-24
July 10, 1952	3.80%	4.66%	4.91%	4.60%
11	4.48	4.75	5.06	4.59
12	3.63	4.43	4.85	3.88
15	3.80	4.13	4.30	4.36
16	3.35	4.15	4.74	4.66
17	4.39	5.24	4.51	5.41
19	3.86	5.25	3.93	4.76
23	3.14	5.13	5.14	5.26
24	3.30	4.66	4.08	4.26
25	3.04	3.55	3.87	4.11
26	2.44	3.93	3.94	3.96
28	4.86	4.36	4.28	4.76
29	4.30	4.65	4.64	4.93
30	7.73	6.65	5.87	4.93
31	6.26	6.64	6.53	6.65
Aug. 1, 1952	5.28	5.91	6.82	6.08
2	6.24	6.67	6.48	7.13
4	5.28	5.90	5.26	5.93
5	4.92	6.17	5.45	5.28
6	6.13	7.76	7.27	6.01
7	5.32	6.01	6.04	6.08
8	5.93	5.88	5.83	5.67
9	4.85	5.33	5.34	5.23
11	4.91	5.83	6.38	6.41
13	6.00	7.30	6.93	7.65
14	6.11	6.26	6.39	6.37
15	4.77	5.28	5.28	5.67
16	5.41	5.04	5.05	5.19
18	3.76	4.57	4.88	4.94
20	5.57	6.68	6.14	6.70
21	6.52	6.59	6.15	5.82
23	4.28	4.99	5.20	4.98
25	7.24	7.75	7.11	6.96
26	6.35	7.12	6.89	8.29
27	4.32	6.13	5.55	5.30
28	3.73	4.88	5.10	5.56
29	6.17	6.00	5.47	5.18
30	4.43	5.60	4.97	4.57

Table 37.--Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Sept. 2, 1952	4.75%	5.62%	5.03%	5.10%
3	4.53	5.74	5.35	5.47
4	3.53	4.49	4.71	4.50
5	5.71	5.02	4.74	5.23
6	3.51	4.56	4.64	4.40
8	3.17	4.30	4.24	4.50
9	6.78	8.01	7.68	8.17
10	4.90	5.64	6.16	6.29
12	5.01	6.00	6.59	6.75
13	4.75	5.32	6.04	6.57
15	5.67	5.57	4.77	5.99
17	4.81	5.48	5.55	5.07
19	3.16	4.66	4.45	4.39
20	5.79	6.46	4.65	4.38
22	6.50	6.07	5.20	5.27
23	6.35	5.09	4.59	4.71
24	8.00	7.12	7.36	8.46
25	5.14	5.24	5.69	4.75
26	6.37	6.44	6.30	6.00
27	5.87	6.28	5.54	5.87
29	6.51	6.67	6.14	5.87
30	6.06	6.16	6.70	7.09
Oct. 1, 1952	6.40	6.66	6.06	6.07
2	6.28	6.40	5.78	5.74
4	4.43	5.23	5.12	5.63
6	4.48	5.81	5.91	5.57
7	8.45	7.46	5.44	7.92
8	7.98	7.60	6.61	7.53
10	4.84	6.45	5.61	6.05
13	4.73	5.30	6.15	5.52
15	5.81	5.50	5.70	5.26
16	5.98	5.45	4.72	4.86
18	7.02	7.40	6.95	7.07
21	5.42	7.31	6.90	6.20
23	6.98	7.00	5.98	5.93
25	5.99	6.04	5.29	5.57
27	6.91	5.39	5.83	5.50
29	5.57	5.70	5.46	5.30
31	4.38	5.03	4.82	4.82
Nov. 1, 1952	4.34	5.02	4.52	4.49
3	3.98	5.41	4.76	4.66

Table 37.—Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Nov. 5, 1952	4.93%	5.06%	4.73%	4.93%
7	3.74	5.36	4.96	4.95
10	4.00	4.13	4.24	4.35
12	3.45	5.02	4.19	4.39
14	3.99	4.50	4.63	3.64
17	3.25	4.45	4.35	4.14
19	3.22	4.58	4.85	4.54
21	6.46	7.12	6.89	7.17
24	5.21	6.08	5.45	6.11
26	3.92	5.12	5.13	5.24
29	4.70	4.30	4.84	4.93
Dec. 1, 1952	5.06	5.06	4.76	5.05
4	4.49	4.78	4.66	4.47
6	4.67	4.94	4.68	4.93
8	3.67	4.51	4.67	4.52
10	3.38	4.01	3.93	4.70
11	5.84	4.68	4.38	4.21
13	5.86	5.29	4.84	4.58
15	5.81	6.34	5.89	5.30
18	6.23	6.43	5.74	5.79
20	5.89	6.67	5.75	5.72
23	5.92	5.82	5.51	5.15
26	5.38	5.64	5.06	5.06
29	6.53	5.32	5.66	5.51
Jan. 2, 1953	6.29	5.93	6.09	5.87
5	7.06	6.68	6.50	6.20
8	5.53	5.78	5.65	5.33
10	6.00	7.72	6.10	7.33
13	4.96	5.79	5.12	----
17	5.17	5.28	5.25	5.27
19	4.50	4.90	5.02	5.18
21	4.62	4.98	4.78	4.20
23	4.32	4.85	4.82	4.30
24	6.78	7.68	5.32	4.27
27	5.18	6.41	6.01	5.43
29	5.08	5.60	5.92	5.24
31	4.19	5.26	5.23	5.16

Table 37.--Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Feb. 2, 1953	5.27%	5.52%	5.19%	5.14%
4	5.58	5.39	5.67	5.98
7	5.39	5.52	5.71	5.35
8	6.77	7.26	6.22	7.63
14	4.83	5.45	5.10	5.26
17	5.79	5.80	5.55	5.03
20	5.70	6.01	5.19	4.17
21	4.06	5.29	5.05	4.76
24	5.85	5.41	4.88	4.87
26	5.60	5.74	5.12	4.49
28	5.17	6.35	5.59	4.82

Table 38. Soil Moisture Changes in Lakeland Fine Sand Resulting from Evaporation at Varying Depths, from July 10, 1952 to February 28, 1953, Expressed as Percentage Soil Moisture (Inside canopy)

Date	Depth(inches) 0-6	6-12	12-18	18-24
July 10, 1952	4.29%	5.08%	5.13%	4.94%
11	5.43	5.06	4.94	4.77
12	4.69	5.19	4.36	4.68
15	3.57	4.79	4.49	4.58
16	4.08	5.86	4.58	4.97
17	4.76	5.20	5.50	4.37
19	4.89	4.60	4.83	4.49
23	4.76	5.52	4.77	4.81
24	3.96	3.96	5.05	4.09
25	3.57	4.34	3.89	3.16
26	3.10	3.73	3.59	3.16
28	3.17	4.93	4.22	4.81
29	3.70	6.04	4.48	5.91
30	9.08	9.36	5.74	6.48
31	4.82	6.05	5.50	5.77
Aug. 1, 1952	6.29	7.65	6.09	5.69
2	5.29	6.79	6.40	7.28
4	3.99	5.58	5.02	5.11
5	4.78	6.61	5.16	5.13
6	6.02	7.28	6.53	5.90
7	7.70	6.17	5.37	5.46
8	7.01	6.18	5.27	5.19
9	4.88	5.76	5.21	5.17
11	6.70	7.36	5.20	4.82
13	7.45	8.54	10.15	6.93
14	6.18	6.53	6.01	6.33
15	4.83	6.09	5.77	5.49
16	5.20	5.50	5.00	5.39
18	3.58	5.15	4.95	4.73
20	7.66	7.41	7.05	5.97
21	7.86	7.23	5.71	5.77
23	4.23	6.31	5.10	4.67
25	8.05	6.87	6.45	5.85
26	9.48	7.52	6.52	6.86
27	6.12	6.83	6.12	6.08
28	6.08	5.95	5.94	6.16
29	5.36	6.28	5.54	4.96
30	6.21	6.28	6.12	5.52

Table 38.--Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Sept. 2, 1952	5.51%	5.13%	4.84%	4.99%
3	2.67	5.45	5.77	5.09
4	4.99	4.77	4.36	3.77
5	4.89	5.36	4.61	5.11
6	3.51	5.70	4.19	4.32
8	3.70	4.36	4.25	3.95
9	4.96	6.99	5.78	4.98
10	4.36	5.29	4.80	5.71
12	7.44	7.93	6.09	4.96
13	6.62	6.52	5.76	5.59
15	6.17	5.98	5.23	4.54
17	4.85	5.33	4.83	4.72
19	3.00	5.59	5.38	4.28
20	6.24	6.34	5.85	5.62
22	5.49	5.83	5.18	5.24
23	5.71	5.65	4.46	4.28
24	6.56	6.89	7.01	6.82
25	5.49	4.31	5.97	6.22
26	6.20	6.36	6.08	6.20
27	6.07	6.64	6.02	4.64
29	6.11	6.26	5.83	5.68
30	8.41	8.23	6.40	5.61
Oct. 1, 1952	7.41	6.67	6.68	6.02
2	8.23	6.75	5.80	6.31
4	5.17	5.69	7.08	5.30
6	6.07	6.39	6.79	6.82
7	6.77	7.73	7.10	6.74
8	6.08	6.74	6.67	5.81
10	4.79	6.57	7.02	6.00
13	5.53	6.13	5.49	5.27
15	4.82	5.42	4.93	5.06
16	4.89	5.26	4.49	4.72
18	7.30	7.89	6.83	8.04
21	5.98	6.10	6.37	5.68
23	6.73	6.53	5.56	5.19
25	4.83	6.16	6.36	3.78
27	5.12	5.10	5.52	5.00
29	5.59	5.82	6.13	5.58
31	4.05	5.00	5.26	5.08

Table 38.—Continued

Date	Depth (inches) 0-6	6-12	12-18	18-24
Nov. 1, 1952	4.33%	4.69%	4.34%	4.93%
3	4.30	5.20	4.23	4.49
5	3.46	5.27	5.19	5.12
7	3.11	4.70	3.70	3.84
10	4.14	4.09	3.77	3.63
12	3.37	4.57	3.90	4.57
14	4.11	4.57	3.78	3.73
17	3.99	5.05	3.61	3.80
19	3.32	4.44	4.74	4.00
21	7.91	8.01	8.13	6.05
24	3.70	5.98	5.18	5.23
26	3.94	4.98	5.11	5.49
29	3.56	4.38	5.31	4.10
Dec. 1, 1952	5.06	5.12	5.25	6.31
4	1.02	6.25	4.36	4.46
6	3.92	4.98	5.90	4.20
8	3.96	4.70	4.57	4.11
10	3.02	4.21	4.67	3.41
11	4.26	4.47	4.64	4.03
13	4.27	5.52	4.91	4.74
15	6.87	5.66	4.95	3.91
18	5.03	5.70	6.37	3.77
20	3.41	3.60	———	———
23	7.73	5.12	4.38	3.98
26	3.54	4.40	4.78	4.50
29	4.91	5.61	5.37	4.39
Jan. 2, 1953	5.91	5.98	6.07	4.59
5	6.55	6.42	5.54	4.69
8	5.11	5.37	5.25	4.60
10	7.27	6.24	5.70	6.17
13	3.62	6.38	5.79	5.40
17	4.54	4.99	5.06	4.98
19	4.40	5.24	4.92	4.41
21	3.43	5.40	4.96	5.47
23	3.65	4.78	4.80	4.32
24	9.86	7.93	5.57	5.31
27	4.61	7.11	6.47	5.84

Table 38.—Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Jan. 29, 1953	3.90%	5.87%	5.49%	5.29%
31	4.65	5.38	5.73	5.25
Feb. 2, 1953	4.82	5.21	5.80	4.87
4	5.48	5.99	5.71	——
7	3.89	5.42	5.05	4.27
8	8.01	7.58	6.04	5.78
14	3.97	5.70	5.98	5.20
17	6.88	6.80	5.67	5.60
20	5.19	6.07	4.75	4.94
21	3.27	5.15	5.91	4.83
24	5.21	5.96	5.12	4.73
26	4.60	5.51	5.30	5.51
28	4.72	5.06	4.47	3.97

Table 39. Soil Moisture Changes in Lakeland Fine Sand Resulting from Evaporation at Varying Depths, from July 10, 1952 to February 28, 1953, Expressed as Percentage Soil Moisture (West)

Date	Depth(inches) 0-6	6-12	12-18	18-24
July 10, 1952	4.87%	4.59%	4.18%	4.48%
11	4.44	4.78	4.54	4.64
12	4.53	5.07	3.94	4.21
15	3.72	4.68	4.23	4.12
16	4.02	4.79	4.35	4.84
17	3.91	3.83	4.68	4.42
19	4.08	4.12	4.00	4.16
23	3.91	4.35	4.34	4.52
24	2.78	3.71	3.79	3.81
25	2.61	3.20	3.54	3.48
26	2.49	3.56	3.61	3.57
28	5.45	4.37	4.26	4.29
29	3.71	4.35	4.03	4.14
30	6.86	5.89	5.78	4.07
31	4.52	4.87	4.94	4.75
Aug. 1, 1952	7.10	5.66	5.88	5.19
2	6.70	6.01	5.92	6.09
4	5.10	4.83	4.70	5.00
5	4.04	5.12	4.45	4.65
6	6.04	7.56	6.40	5.92
7	5.95	4.87	5.29	5.70
8	6.91	5.25	4.64	4.66
9	5.47	4.90	4.39	4.84
11	5.62	5.05	4.85	6.01
13	7.68	7.23	6.83	6.57
14	4.87	5.04	5.28	5.27
15	4.54	4.89	4.69	4.59
16	4.83	4.46	4.38	4.57
18	5.07	4.63	4.46	4.47
20	5.61	5.45	4.86	5.32
21	6.93	5.44	5.29	5.11
23	4.21	4.69	4.54	4.10
25	6.71	6.63	5.99	5.56
26	7.16	6.78	5.98	6.59
27	4.73	5.50	5.29	4.58
28	4.21	4.89	4.74	5.11
29	4.87	4.94	4.78	4.96
30	5.03	4.94	4.87	4.67

Table 39.--Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Sept. 2, 1952	3.75%	4.06%	4.13%	4.18%
3	3.16	4.07	4.13	4.40
4	2.60	4.01	3.76	3.69
5	3.90	4.09	3.91	3.95
6	3.98	3.65	3.96	3.87
8	2.60	2.74	3.48	3.63
9	7.18	5.64	4.87	4.18
10	4.06	3.09	3.84	4.05
12	4.95	4.88	4.05	3.78
13	4.88	6.03	4.79	4.63
15	3.98	4.70	4.56	4.70
17	4.48	4.18	4.27	4.17
19	2.83	3.56	2.79	3.34
20	3.83	3.99	4.33	4.28
22	5.78	4.51	3.95	4.22
23	4.36	3.87	3.90	3.81
24	7.06	6.37	6.19	5.87
25	5.21	5.90	4.99	5.41
26	5.07	5.80	4.73	4.60
27	4.73	5.67	4.47	4.61
29	5.26	5.19	5.08	4.59
30	6.19	5.99	4.95	5.12
Oct. 1, 1952	6.36	6.88	5.74	5.87
2	5.43	5.66	5.43	5.48
4	4.57	4.77	4.73	5.06
6	4.40	5.03	4.40	4.95
7	7.78	7.47	6.52	5.90
8	6.43	6.89	5.81	5.58
10	5.46	4.94	5.28	4.99
13	4.52	4.88	4.74	5.06
15	4.84	4.73	4.23	4.18
16	5.59	4.72	4.21	4.19
18	6.45	7.02	5.98	6.15
21	6.17	6.19	6.03	6.20
23	6.06	5.72	5.01	4.96
25	3.12	4.76	4.91	4.22
27	4.59	4.03	4.19	4.37
29	4.36	4.03	4.97	4.22
31	3.91	4.41	4.11	4.00

Table 39.—Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Nov. 1, 1952	3.26%	4.29%	3.95%	3.83%
3	2.96	3.72	4.30	3.82
5	3.67	3.92	3.88	3.92
7	3.62	4.20	3.93	3.97
10	3.35	3.46	3.57	3.36
12	2.29	4.21	3.73	3.48
14	3.23	4.12	3.67	3.72
17	2.65	3.35	3.20	3.23
19	3.01	3.94	3.88	3.11
21	6.04	6.27	6.21	5.43
24	4.51	4.75	4.89	4.91
26	2.85	3.91	4.87	4.60
29	3.78	4.08	4.06	4.38
Dec.1, 1952	4.82	4.17	4.29	4.27
4	2.24	3.15	3.90	3.60
6	4.24	3.95	3.61	3.86
8	3.23	4.42	4.18	3.90
10	1.80	3.82	3.55	3.22
11	5.40	4.26	4.06	3.77
13	4.65	4.83	4.70	4.17
15	5.20	5.45	4.74	4.89
18	5.03	5.07	4.58	4.71
20	3.57	4.66	4.29	4.62
23	4.69	4.56	4.59	5.42
26	3.26	4.32	3.94	4.50
29	4.98	5.17	4.99	5.51
Jan. 2, 1953	5.57	5.48	5.15	5.65
5	5.71	5.69	5.21	5.32
8	5.10	5.06	4.99	4.89
10	5.64	6.35	6.11	6.09
13	4.20	4.68	4.87	5.10
17	4.10	4.68	4.24	4.43
19	3.57	4.77	3.68	4.50
21	3.24	4.21	3.94	3.85
23	3.13	4.15	4.21	3.92
24	8.75	7.91	8.04	4.89
27	4.54	5.32	5.45	5.80
29	4.55	4.80	4.87	5.19
31	3.83	5.02	4.71	4.89

Table 39.--Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Feb. 2, 1953	3.80%	4.37%	4.48%	4.60%
4	6.13	5.86	5.33	5.25
7	4.09	4.81	4.93	4.89
8	6.67	6.50	5.98	5.50
14	4.54	5.07	4.49	4.66
17	5.62	6.10	5.89	5.57
20	4.24	5.32	5.13	5.14
21	3.90	5.61	5.05	5.04
24	5.12	5.45	5.06	5.74
26	3.85	4.35	4.17	4.40
28	4.56	4.47	4.53	4.85

Table 40. Soil Moisture Changes in Lakeland Fine Sand Resulting from Evaporation at Varying Depths, from July 10, 1952 to February 28, 1953, Expressed as Percentage Soil Moisture (East)

Date	Depth(inches) 0-6	6-12	12-18	18-24
July 10, 1952	4.75%	4.83%	4.49%	4.41%
11	4.22	4.74	4.12	4.63
12	4.29	4.21	4.05	4.63
15	3.15	4.35	4.54	4.16
16	3.53	3.95	4.24	4.04
17	3.78	4.23	4.15	3.96
19	3.75	4.66	4.10	3.85
23	4.17	5.10	4.47	4.35
24	3.50	4.26	4.62	4.19
25	3.57	3.79	3.94	3.61
26	1.90	4.49	4.19	4.02
28	5.26	4.81	4.21	4.25
29	3.82	5.35	4.29	4.28
30	8.63	6.57	6.41	6.55
31	4.82	6.15	5.20	5.14
Aug. 1, 1952	7.42	6.88	6.65	7.09
2	6.35	6.99	5.91	6.67
4	5.04	6.02	5.31	4.84
5	5.35	5.66	4.87	4.83
6	7.13	7.23	5.62	5.23
7	6.20	5.99	5.24	4.15
8	5.14	5.36	6.14	6.12
9	5.78	5.74	5.60	4.87
11	6.29	6.20	5.45	4.79
13	8.31	7.44	6.53	5.73
14	6.84	6.58	5.83	6.14
15	4.83	6.02	5.50	5.44
16	4.56	5.84	5.04	4.94
18	4.43	4.65	5.11	4.89
20	6.19	5.67	5.13	5.45
21	6.16	6.28	5.38	5.03
23	3.90	4.18	4.95	4.91
25	8.16	7.31	6.61	6.27
26	8.61	7.66	6.53	7.03
27	5.92	6.42	5.39	5.94
28	4.44	6.25	5.35	5.74
29	6.62	6.19	5.17	4.96
30	5.27	5.40	5.00	4.63

Table 40.--Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Sept. 2, 1952	3.64%	5.41%	4.99%	4.24%
3	3.64	4.75	3.99	3.99
4	3.93	4.27	4.22	4.42
5	4.77	5.35	4.31	4.18
6	4.48	5.19	4.15	4.62
8	2.57	3.71	3.86	3.83
9	8.04	7.56	6.86	6.27
10	4.95	6.19	5.19	5.19
12	5.57	6.56	5.74	4.71
13	5.30	6.98	6.12	5.76
15	5.29	5.49	5.05	5.47
17	4.05	5.84	5.11	5.15
19	3.93	4.05	4.30	4.34
20	6.46	6.07	4.92	4.75
22	7.53	6.12	4.78	4.92
23	4.63	5.91	4.49	4.17
24	6.81	7.97	6.34	7.15
25	5.75	5.66	5.78	5.28
26	5.23	6.40	4.23	4.88
27	4.86	6.64	4.08	4.87
29	6.20	7.41	5.82	5.36
30	6.98	7.47	7.19	6.31
Oct. 1, 1952	6.30	6.89	5.55	6.05
2	6.70	6.20	5.19	5.78
4	5.21	6.65	5.07	4.62
6	5.43	4.80	5.01	5.03
7	7.35	8.14	7.31	7.63
8	7.46	8.95	5.92	5.82
10	4.97	5.53	5.22	5.33
13	5.14	5.41	4.67	4.86
15	3.95	6.06	4.61	4.73
16	5.77	5.10	4.54	4.53
18	8.00	7.17	6.48	6.87
21	5.40	6.72	5.58	5.32
23	6.69	7.83	5.78	5.03
25	4.76	5.02	5.18	4.80
27	6.22	5.14	4.70	5.36
29	4.60	5.60	4.49	4.30
31	4.81	5.07	4.80	5.15

Table 40.—Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Nov. 1, 1952	3.56%	4.75%	4.59%	3.81%
3	3.74	5.38	4.75	4.99
5	4.17	4.80	4.13	4.06
7	4.23	4.97	4.73	4.38
10	3.07	4.90	3.88	3.93
12	3.71	4.35	4.09	3.65
14	3.69	4.65	4.89	4.42
17	4.00	4.68	4.02	3.57
19	3.11	2.78	4.65	3.68
21	5.95	6.95	6.71	6.80
24	4.81	5.52	5.12	5.31
26	3.02	5.21	4.86	5.44
29	4.21	5.39	4.69	4.60
Dec. 1, 1952	3.41	5.08	4.09	4.24
4	3.25	5.13	4.64	4.70
6	6.23	6.08	4.33	5.62
8	3.81	4.99	3.96	4.02
10	2.38	3.98	3.92	3.86
11	4.89	4.91	4.03	3.73
13	3.83	5.51	4.17	3.26
15	5.98	5.46	4.70	3.96
18	5.64	5.62	5.13	4.81
20	5.07	5.66	4.85	4.41
23	5.39	6.44	5.71	4.98
26	4.10	5.52	4.65	4.35
29	5.23	5.39	5.02	4.84
Jan. 2, 1953	3.48	5.49	4.60	4.45
5	5.38	6.58	5.28	4.92
8	4.78	5.01	4.73	4.78
10	5.93	5.70	5.83	6.30
13	3.39	4.68	4.86	5.53
17	3.27	5.29	4.99	4.75
19	3.23	4.32	4.60	4.44
21	4.77	4.79	4.12	4.31
23	4.53	4.65	4.35	4.33
24	6.23	5.15	4.71	4.07
27	4.49	5.70	4.86	4.36
29	3.85	6.18	4.44	4.84
31	3.78	5.42	4.45	4.42

Table 40.—Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Feb. 2, 1953	5.07%	5.21%	4.67%	4.45%
4	5.62	5.95	5.43	4.70
7	2.97	3.78	4.57	3.82
8	6.69	6.84	6.79	7.02
14	4.27	5.83	5.22	4.86
17	5.37	5.51	4.92	4.40
20	4.50	4.34	4.52	4.39
21	3.46	4.26	4.83	4.59
24	4.08	5.19	4.54	4.08
26	4.40	5.16	4.45	4.24
28	3.58	4.93	4.32	4.03

Table 41. Soil Moisture Changes in Lakeland Fine Sand Resulting from Evaporation at Varying Depths, from July 10, 1952 to February 28, 1953, Expressed as Percentage Soil Moisture (South)

Date	Depth(inches) 0-6	6-12	12-18	18-24
July 10, 1952	4.01%	4.48%	4.72%	4.64%
11	4.91	5.72	6.47	5.24
12	3.09	4.84	4.95	5.44
15	4.46	5.42	4.47	4.43
16	2.25	4.69	4.72	4.81
17	3.25	4.61	4.82	5.04
19	2.51	5.04	4.31	4.40
23	3.41	4.27	4.54	4.47
24	2.86	4.03	4.05	3.91
25	2.37	3.72	3.71	4.32
26	3.86	3.80	3.79	2.86
28	4.38	4.18	4.01	4.08
29	3.33	3.96	3.42	3.91
30	5.29	6.36	6.64	6.72
31	3.81	5.32	6.59	7.33
Aug. 1, 1952	5.12	5.68	5.69	6.06
2	5.30	6.24	6.06	6.53
4	3.87	4.95	4.81	5.06
5	3.31	4.80	4.73	4.81
6	5.61	6.70	6.29	6.00
7	4.02	5.43	5.51	5.55
8	4.75	5.38	5.34	5.40
9	4.20	4.87	4.88	4.80
11	4.76	6.27	6.34	6.36
13	5.08	6.09	6.43	6.72
14	3.37	5.19	5.16	5.54
15	2.90	4.22	4.73	4.94
16	2.92	4.41	4.65	4.46
18	3.52	4.29	4.17	4.32
20	3.17	4.98	5.45	5.51
21	4.92	5.27	4.85	5.12
23	2.30	4.00	3.79	4.49
25	5.62	5.42	5.91	5.29
26	5.20	6.30	6.39	7.09
27	3.29	5.60	5.18	5.24
28	3.55	4.57	4.52	5.61
29	4.93	4.98	4.72	5.10
30	3.50	4.43	4.07	4.41

Table 41.—Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Sept. 2, 1952	2.64%	3.99%	3.32%	3.25%
3	2.04	3.83	4.57	4.34
4	1.37	2.98	2.66	3.65
5	2.47	3.45	3.95	3.97
6	3.07	4.00	3.86	3.80
8	2.84	3.57	2.99	3.51
9	3.99	6.32	6.30	5.94
10	2.62	4.79	5.64	6.15
12	2.97	4.96	5.52	5.57
13	3.67	4.71	5.41	5.06
15	2.92	4.40	4.58	5.15
17	2.47	2.61	4.12	4.65
19	2.77	4.44	4.01	4.09
20	2.11	3.88	4.36	4.61
22	2.04	4.81	4.15	4.15
23	4.48	4.33	4.13	4.11
24	4.57	5.57	6.91	6.99
25	4.72	3.53	4.97	5.04
26	4.79	5.40	5.00	5.21
27	3.29	5.32	4.94	5.32
29	5.20	5.63	5.14	4.98
30	5.84	7.23	6.44	6.67
Oct. 1, 1952	5.33	5.97	5.69	5.64
2	6.77	4.99	5.14	5.26
4	3.82	4.98	4.46	4.55
6	3.84	4.29	2.93	4.00
7	6.10	6.36	6.17	7.05
8	6.46	6.21	5.57	5.79
10	4.26	5.11	5.19	5.33
13	2.87	3.98	4.09	4.31
15	3.09	4.78	4.26	4.39
16	4.20	4.51	4.15	4.20
18	5.45	6.15	6.00	6.83
21	4.98	5.14	5.41	5.61
23	6.04	5.54	5.33	5.00
25	3.18	4.28	5.15	4.59
27	5.37	5.00	4.38	4.57
29	2.81	4.51	4.69	4.79
31	2.53	4.21	3.76	4.11

Table 41.—Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Nov. 1, 1952	2.44%	4.09%	3.85%	3.79%
3	2.53	3.41	3.96	4.40
5	3.70	4.06	4.77	3.96
7	2.06	3.36	3.86	3.60
10	1.99	3.30	3.56	3.91
12	3.94	3.80	3.74	3.32
14	2.07	3.80	3.88	4.15
17	1.23	2.82	2.56	3.46
19	2.47	3.94	3.88	3.92
21	5.43	6.23	6.55	5.38
24	3.33	4.83	4.98	5.34
26	3.03	4.65	4.71	4.72
29	3.88	4.44	4.74	5.03
Dec. 1, 1952	2.53	4.02	4.06	4.24
4	2.81	3.74	4.56	4.65
6	2.20	3.98	3.81	4.33
8	3.26	4.11	4.37	4.64
10	1.73	3.78	4.51	4.36
11	4.15	3.96	3.71	4.00
13	3.96	4.38	4.60	4.73
15	4.59	6.08	5.45	4.42
18	3.35	5.46	5.62	5.80
20	3.22	4.49	5.28	5.34
23	4.70	4.74	5.52	4.61
26	2.58	4.17	4.55	4.68
29	3.87	4.96	5.29	6.04
Jan. 2, 1953	4.01	6.16	4.97	6.36
5	3.79	5.19	5.78	5.97
8	3.40	4.73	5.02	5.38
10	5.07	4.37	5.84	6.48
13	3.05	4.12	4.42	4.90
17	2.95	4.19	4.39	5.05
19	3.54	4.21	3.93	4.22
21	2.64	4.08	4.60	4.95
23	2.51	4.37	4.54	4.69
24	6.69	7.39	6.77	5.44
27	2.94	5.00	5.49	5.49
29	2.59	4.34	4.43	4.84
31	2.78	4.39	4.54	5.14

Table 41.--Continued

Date	Depth(inches) 0-6	6-12	12-18	18-24
Feb. 2, 1953	3.83%	4.24%	4.16%	4.79%
4	4.67	5.93	5.34	5.16
7	2.95	4.76	4.29	4.91
8	4.73	5.78	6.29	7.03
14	2.68	4.41	4.81	5.06
17	4.81	5.71	5.55	5.17
20	4.50	4.34	4.52	4.39
21	3.01	6.09	4.93	4.62
24	3.77	4.44	4.54	4.41
26	3.21	4.30	4.49	4.69
28	2.73	4.47	4.15	4.60

Table 42. Analysis of Variance: Percentage Soil Moisture at Different Depths at Permanent Wilting Percentage on Lakeland Fine Sand

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	"F" Values
Total	39	0.5406	0.0139	
Depth	3	0.3185	0.1062	17.41**
Replication	9	0.0561	0.0062	1.02
Error	27	0.1160	0.0061	

Least Significant Difference required between depths

Mean: 1% = 0.1522
5% = 0.1127

Table 43. The Apparent Density of Lakeland Fine Sand in the Upper 24 Inches Measured at 6 Inch Intervals

Depth (inches)	Replications					Average
	one	two	three	four	five	
0- 6	1.45	1.44	1.42	1.49	1.52	1.46
6-12	1.55	1.51	1.43	1.53	1.51	1.51
12-18	1.59	1.52	1.53	1.59	1.54	1.55
18-24	1.51	1.51	1.54	1.57	1.50	1.53

BIOGRAPHICAL ITEMS

Robert Chung-jen Koo was born on March 20, 1921 in Shanghai, China. After finishing his high school education in Medhurst Middle School, Shanghai, he came to the United States and enrolled in the University of Tennessee Junior College at Martin, Tennessee in September 1940. In September 1942 he transferred to Cornell University at Ithaca, New York, where he received his B.S. degree in Horticulture in June, 1944.

Following his graduation from college, he was employed by the U. S. Government and assigned to the U. S. Marine Corps, based in China and islands of the Pacific, for the next three years. On returning from China in 1948 he enrolled at the Ohio State University as a special student.

He entered the University of Florida in September 1949. He received his Master of Agriculture degree from the University of Florida in June, 1950. Since that time he has pursued his studies in the University of Florida leading to a degree of Doctor of Philosophy.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of the committee. It was submitted to the Graduate Council and was approved as partial fulfilment of the requirements for the degree of Doctor of Philosophy.

Date _____

C. V. Noble
Dean, College of Agriculture

R. E. Lantz
Dean, Graduate School

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